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COCKPIT CONTROL SYSTEM

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1.1 PROJECT SUMMARY

The purpose of this project is to provide a detail design for the cockpit control system of the Viper PFT. The statement of work for this project requires provisions for control of the ailerons, elevator, rudder, and elevator trim. The system should provide adjustment for pilot stature, rigging and maintenance. MIL-STD-1472 is used as a model for human factors criterion. The system is designed to the pilot limit loading outlined in FAR part 23.397. The general philosophy behind this design is to provide a simple, reliable control system; which will withstand the daily abuse that is experienced in the training environment without excessive cost or weight penalties.

RUDDER			
COMPONENT	f_{max} (psi)	MARGIN OF SAFETY	PAGE #
Toe Pedal	7541	1.65	Appendix
Rod & Casting	4655	3.30	Appendix
Pedal Actuated Crank	16076	.7	Appendix
Bottom Mount	6024	2.32	Appendix
Center Cast	8639	2.16	Appendix
Center Mount	17278	.15	Appendix

Table 1: Rudder Analysis

ELEVATOR STRESS ANALYSIS							
	f_{MAX}	FITTING FACTOR	f_{LL} (psi)	FACTOR OF SAFETY	f_{UL} (psi)	MARGIN OF SAFETY	PAGE #
Support Column	15504	1.2	18605	1.5	27908	1	12
Bolt Case 1	902	1.2	1082	1.5	1623.6	1.51	14
Bolt Case 2	2204	2	4404	1.5	6606	.41	14
Joiner	1803	1.4	2524	2	5048	10.1(Y) 6.13(U)	14

*** The margin of safety at yield was only calculated for the weakest spot ie, the joiner, see drawing AE421S93ADP01-3

	f_{max} (psi)	FITTING FACTOR	f_{LL} (psi)	FACTOR OF SAFETY	f_{UL} (psi)	MARGIN OF SAFETY	PAGE #
Control Yoke(s)	4074	2	8146	1.5	12222	4.64	11
Control Yoke (brg)	13250	2	26500	1.5	51200	.4	11
Rods	11459	1.2	13571	1.5	27501	1.04	15

Table 2: Elevator Stress Analysis

AILERONS			
COMPONENT	f_{MAX} (psi)	MARGIN OF SAFETY	PAGE #
Sprocket 1 & 2	21281	1.97	20
Sprocket 3	3396	17.74	21
Pulleys 5 & 6	17195	3.70	21

Table 3: Aileron Stress Analysis

2.0 RUDDER CONTROL SYSTEM

2.1 Description

The rudder control system provides rudder and nosewheel deflection of $\pm 20^\circ$ as well as differential braking. The differential braking is composed of a separate master cylinder, parking brake and valve (see figure in appendix). Pilot input is transferred from two sets of bottom pivoting rudder pedals, through a series of push-pull rods and bellcranks, which are routed through the driveshaft tunnel.

2.2 Loads and Loading

2.2.1 The toe brake structure pivots on a bearing at point A. A 200 lb. load supplied by the pilot generates reactant forces at A and B. The following calculation is when the master cylinder is fully compressed.

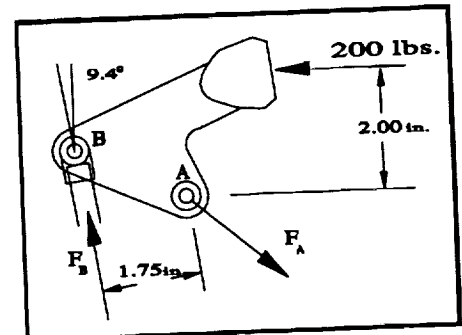


Figure 2.2.1

Summing the moments about point A;

$$\sum M_A = 0$$

$$200 \text{ lbs.} \times 2.00 \text{ in.} - F_B \times 1.75 \text{ in.} = 0$$

$$F_B = 228.6 \text{ lb}$$

Summing the forces in the X and Y plane;

$$\sum F_X = 0$$

$$F_{Ax} - 200 \text{ lbs.} - 228.6 \text{ lbs.} \times \sin 9.4 = 0$$

$$\sum F_Y = 0$$

$$228.6 \text{ lbs.} \times \cos 9.4 - F_{Ay} = 0$$

$$F_A = \sqrt{F_{Ax}^2 + F_{Ay}^2}$$

$$F_A = 282.8 \text{ lbs.}$$

2.2.2 The largest value for F_C and F_D occur when the pedal is in the neutral position. A pilot's force of 200 lbs. is applied at the toe brake to create the largest moment. Summing moments about point C and the forces in the horizontal plane;

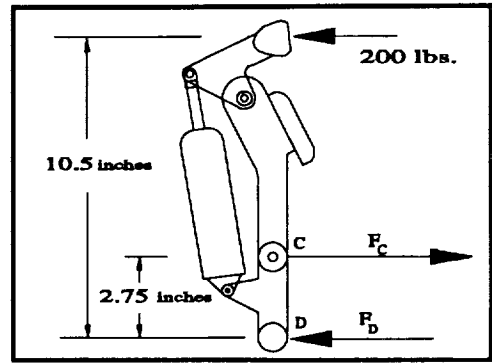


Figure 2.2.2

$$F_D \times 2.75 \text{ in.} - 200 \text{ lbs.} \times 7.75 \text{ in.} = 0$$

$$F_D = 563.6 \text{ lbs.}$$

$$F_C - 200 \text{ lbs.} - 563.6 \text{ lbs.} = 0$$

$$F_C = 763.6 \text{ lbs.}$$

2.2.3 Pedal Mount

$$\sum F_X = 0$$

$$563.6 \text{ lbs.} - 4F_{\text{bolt}} = 0 \quad F_{\text{bolt}} = 141 \text{ lbs.}$$

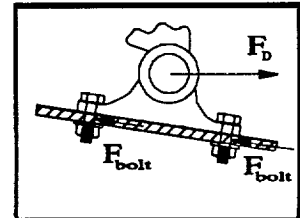


Figure 2.2.3

2.2.4 Rod Assembly

A load of 763.4 lbs. is carried through the rod connecting casting, rod, and the rod ends that attach to the pedal actuated crank.

2.2.5 Pedal Actuated Crank

The bell-cranks' maximum load occurs when the pilot uses full braking on both pedals; therefore, F_{CENTER} and F_{GEAR} are equal to 0.

$$\sum F_x = 0$$

$$763.6 \text{ lbs.} + 763.6 \text{ lbs.} - F_{PIVOT} = 0$$

$$F_{PIVOT} = 1527 \text{ lbs.}$$

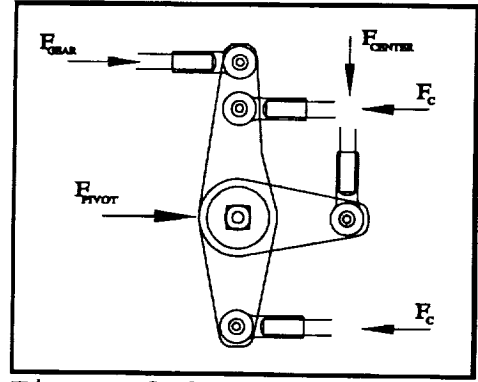


Figure 2.2.4

2.2.6 Center Rod

The maximum axial load is 736.6 lbs.. This occurs with complete resistance to pilot load on one pedal.

2.2.7 Center Crank

The limiting case occurs when both pilots act in unison.

$$\sum M_{PIVOT} = 0 \quad F_{CENTER} 2.5 - F_{ROD} 2.5 = 0$$

$$F_{ROD} = 1527 \text{ lbs.}$$

$$F_{PIVOT} = \sqrt{1527^2 + 1527^2} \quad F_{PIVOT} = 2160 \text{ lbs.}$$

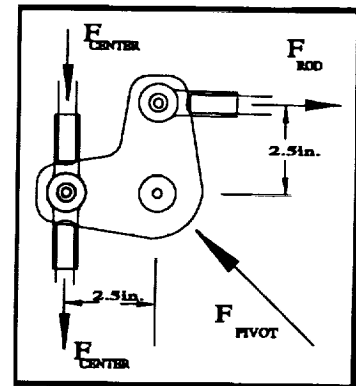


Figure 2.2.5

2.3 Substantiation

Toe Brake Pedal						
Figure 2.2.1	t (In)	F.F.	f_{brg}	$f_{t.o.}$	M.S. _{LL}	M.S. _{U.L}
Point A	.30	2.0	7541	3771	1.65	1.83
Point B	.25	2.0	7315	3658	1.73	1.92

Table 2.3.1 Toe Brake Pedal

Lower Pedal							
Figure 2.2.2	t (In)	d (In)	f_{brg} (psi)	$f_{t.o.}$ (psi)	f_s (psi)	M.S. _{LL}	M.S. _{U.L}
Point A	.25	.656	1724	N/A	N/A	10.6	11.4
Point B	.25	N/A	3658	1829	N/A	4.47	4.83
Point C	1.79	N/A	3413	1706	N/A	4.86	5.25
Point D	.25	.75	N/A	N/A	638	30.4	32.4

Table 2.3.2 Lower Pedal

Pedal Mount						
	t(In)	d(In)	f_{brg} (psi)	$f_{t.o.}$ (psi)	M.S. _{LL}	M.S. _{U.L}
Figure 2.2.3	1.0	1.3	434	1127	16.7	17.9

Table 2.3.3 Pedal Mount

Rod End Casting				
t(In)	d(In)	f_{brg} (psi)	M.S. _{LL}	M.S. _{U.L}
.25	.656	4655	3.3	3.94

Table 2.3.4 Rod End Casting

Rod						
Length (In)	A(In ²)	I(In ⁴)	f _{comp} (psi)	f _{crit} (psi)	M.S. _{LL}	M.S. _{UL}
6.00	.06943	.001786	10998	2116	5.82	4.76

Table 2.3.5 Rod

Rod End		
F _{LL} (lbs)	M.S. _{LL}	M.S. _{UL}
3025	2.96	1.64

Table 2.3.6 Rod End

Pedal Actuated Crank						
Figure 2.2.4	t (In)	f _{brg} (psi)	f _{Lo.} (psi)	M.S. _{LL}	M.S. _{U.L}	
Point A & C	.19	16076	4257	1.55	.70	
Point B	.19	5358	2297	6.65	4.1	
Point D	.19	11253	2993	2.64	1.43	
Point E	.19	16076	4019	1.55	.70	
Crank Assembly In Bending						
Moment Arm(In)	C (In)	I (In ⁴)	S.C Factor	f _{Bending} (psi)	M.S. _{LL}	M.S. _{U.L}
7.0	1.25	.261	3.0	40512	1.23	.053

Table 2.3.7 Pedal Actuated Crank

Bottom Mount					
	f_{tens} (psi)	f_{brg} (psi)	$f_{Lo.}$ (psi)	M.S. _{LL}	M.S. _{U.L}
Pivot	4122	6024	2447	2.23	2.54
Bolts	N/A	3054	3054	5.55	5.98

Table 2.3.8 Bottom Mount

Top Mount			
f_{tens} (psi)	f_{brg} (psi)	M.S. _{LL}	M.S. _{U.L}
4122	6024	2.23	2.54

Table 2.3.9 Top Mount

Center Rod						
Area (in ²)	Length (in)	I (in ⁴)	f_{comp} (psi)	f_{crit} (psi)	M.S. _{LL}	M.S. _{U.L}
.06943	9.00	.001786	10998	94000	5.82	4.76

Table 2.3.10 Center Rod

Center Crank					
Figure 2.2.5	f_{tens} (psi)	f_{brg} (psi)	$f_{Lo.}$ (psi)	M.S. _{LL}	M.S. _{U.L}
Point A & C	N/A	24435	8551	.678	.119
Point B	5759	8639	5759	3.75	2.16

Table 2.3.11 Center Crank

Center Crank Mount					
	f_{tens} (psi)	f_{brg} (psi)	$f_{t.o.}$ (psi)	M.S. LL	M.S. U.L
Pivot	2160	17278	1439	.158	.235

Table 2.3.12 Center Crank Mount

2.4 Manufacturing and Maintenance

Aluminum castings are utilized in the manufacture of most components in the system. The casting alloy is 355.0-T6, which is a light weight, high strength casting alloy. The pedal actuated crank and center crank are fabricated from 2024-T6 aluminum plate. The push pull rods are one half inch O.D. 4130 steel tubing. All other components are aircraft approved vendor supplied hardware, including the braking system.

3.0 ELEVATOR CONTROL SYSTEM (ECS)

3.1 Description

The elevator control system was designed using the loading conditions listed in FAR Part 23 and the human factors specifications given in MIL-STD-1472 Appendix Two. The first step in the design analysis was to determine how the elevator control system would function. As is typical in most aircraft, the pilot would exert a force on the control yoke, which would transfer the motion horizontally to the control support column, which would then transmit the load to push pull rods, which connect to a bellcrank with dual universal joints that were connected to yet another rod which facilitates the proper deflection angle with a maximum angle of $\pm 20^\circ$. The next step was to organize the elevator control system into workable sections. These sections are as follows:

1. The adjustable control yoke shaft
2. The control column support (including the pivot point)
3. The actual push-pull rod assembly with interface to the elevator
4. The elevator trim

After defining each section of the ECS, the sections were thoroughly researched using typical single engine models like the Cessna 172, the Mooney and the Piper Cadet(Warrior). With this accomplished, it was time to begin the structural substantiation and material selection. For clarity, each of the sections mentioned above will be discussed individually.

3.2 Adjustable Control Yoke

The control yoke with adjustable arm was a unique idea conceived for the discriminating pilot who is not of "standard" height and arm length. The adjustable control yoke shown below, allows the pilot to achieve proper elevator deflection by compensating for his/her arm length. The control yoke can be made longer for a pilot with long arms and shorter for a pilot who has shorter arms.

This increases the pilot's comfort as well as his safety, because proper deflection can be made. The control yoke is adjusted by pushing in and simultaneously turning the fastener and moving the

inner shaft to the proper location, which is determined by the pilot's arm length, then releasing the fastener, which allows the steel pin to lock into position. This adjustment method was chosen primarily for its safety features. With the two motions required to relocate the pin, it seems unlikely that pin will be able to displace if bumped or knocked during flight.

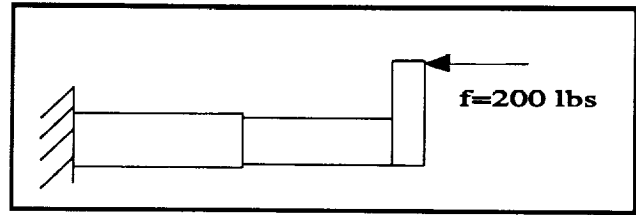


Figure 3.2.1

3.2.1 Substantiation

The adjustable control yoke was designed using the worst case scenarios of loading, ie. a 200lb force is exerted by the pilot, which is represented in figure 3.2.1. The 200 lb load will be transmitted directly through the control yoke shaft to the control column support. Of major interest is the pin attachment. The table below summarizes the results of the calculations.

Pin Attachment					
f_{Shear} (psi)	f_{brg} (psi)	F.F.	F.S.	M.S. _{LL}	M.S. _{UL}
4074	12800	2.0	1.5	9.06	.40

Table 3.2.1 Pin Attachment Stress Summary

3.2.2 Manufacturing and Maintenance

The inner and outer shafts are made of extruded Aluminum 2219 and are engaged such that buckling will not be a problem. Located at the intersection of the dash and the control yoke is casted "dash interface" designed to provide horizontal support. A universal joint is located approximately 6 in from the interface to allow the control yoke to move horizontally with no vertical displacement, while the control column support moves radially 10.9°. The displacement of the control yoke is negligible as shown from the following calculations.

$$\delta = f/G = 200 \cdot 33 / 3843197 \rightarrow \delta = .0017 \text{ in.}$$

The control yoke is welded to the control column support with a needle-thrust point ball bearing to facilitate turning motion necessary for the ailerons.

3.3 CONTROL COLUMN SUPPORT

Essential to the ECS is the control column support shaft, shown in figure 3.3.1. The control column support shaft function is to pivot around the base point when the control yoke is pulled out or pushed in, thus transferring motion to the push-pull rods located approximately 3 in. above the base point.

3.3.1 Loads and Loading

This part was designed for the two worst case scenarios that the support column will encounter; 1) both pilots pushing or pulling with a 200 lb force each or 2) one pilot pulling while the others pushes with a 200 lb force each. The support column was analyzed by breaking it into three members, 2 vertical and 1 horizontal. The static analysis is shown

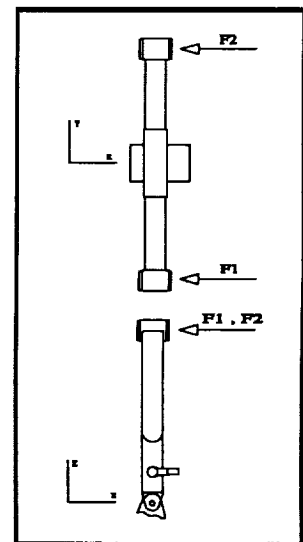


Figure 3.3.1

below, where H = Reaction load and E = load that the push-pull rod will see.

$$\Sigma F_x = 0 \quad 2*200 - E - H = 0 \quad \Sigma M_y = 2*200*16.8 - E - H = 0 \rightarrow E = 2203 \text{ lbs.} \quad H = 1803 \text{ lbs.}$$

The results for the members are tabulated below.

3.3.2 Substantiation

Case	Member	Shear(psi)	Moment	Torque
# 1	#1	200	1980	
	#2	400	4520	1980
	#3	2203	5179	
# 2	#1	200	1980	
	#2	200	2260	3960
	#3	0	0	4520

* Denotes maximum values that were designed to

Table 3.3.2 Control Column Support Stress Analysis

The calculations shown below substantiate that the control column support can be made of extruded Aluminum 2219 and that AN4C-24 bolts can be used to connect the control column joiner to the control column attachment plate.

$$\begin{aligned} f_{\max 1} &= Tc/J \\ &= 4520*1/.57 \\ f_{\max 1} &= 2879 \text{ psi} \end{aligned}$$

$$\begin{aligned} f_{\max 2} &= MC/I \\ &= 5179*1/.785 \\ f_{\max 2} &= 6597 \text{ psi} \end{aligned}$$

$$\begin{aligned} f_{\max 3} &= VQ/It \\ &= 2203*.537/.785*.25 \\ f_{\max 3} &= 6028 \text{ psi} \end{aligned}$$

$$\Sigma F = f_{\max 1} + f_{\max 2} + f_{\max 3} = 15504 \text{ psi} \rightarrow f_{LL} = 1.2*\Sigma f_{\max} \rightarrow M.S._{yield} = 36000/18605 - 1 = .93$$

$$\rightarrow f_{UL} = 1.5*f_{LL} \rightarrow M.S._{ult} = 56000/27908 - 1 = 1.0$$

The maximum load for the bolts will be found at point E (push-pull rod location). Four bolts will have to sustain 3606 psi. Thus, each bolt will see 902 psi.

$$\Sigma F_x = 0 \quad V - 1803/2 = 902 \text{ psi} \rightarrow f_{LL} = 1.2 * V = 1082 \text{ psi} \rightarrow f_{UL} = 1.5 * f_{LL} = 1623.6 \text{ psi} \rightarrow$$

$$\text{M.S.} = (F_{tu} / f_{ul}) - 1 = 4080/1623.6 - 1 = 1.51$$

The weakest spot will be where the control column attachment plate , which will be machined as well as the control column joiner, is welded to the aircraft structure. The substantiation calculations are shown below.

$f = P/A$	$F.F. = 1.2 + .2 \text{ (weld)}$	$f_{LL} = F.F * f$	$f_{UL} = F.S. * f_{LL}$
$= 1803/2 * .5$	$= 1.4$	$= 1.4 * 1803$	$= 2.0 * 2524$
$f = 1803 \text{ psi}$	$F.F. = 1.4$	$f_{LL} = 2524 \text{ psi}$	$f_{UL} = 5048 \text{ psi}$

$$\text{M.S.}_{\text{yield}} = 36000/5048 - 1$$

$$\text{M.S.}_{\text{yield}} = 6.13$$

$$\text{M.S.}_{\text{ul}} = 56000/5048 - 1$$

$$\text{M.S.}_{\text{ul}} = 10.1$$

3.4 PUSH-PULL ROD ASSEMBLY

The push-pull rods were selected for the D-2 for several reasons. First the push-pull rods have a "better" feel to them thus the student pilot has a better idea of the deflections necessary to create proper elevator motion. Second, the push-pull rods, have a greater coefficient of thermal expansion than the traditional cable. This is an important factor considering that the ECS is located several inches below the engine. These push-pull rods are connected to the control column support by means of a NAS-660-R4-11 rod end. The rods are extruded 4130 Steel and will see a load of 2200 lbs, see control column calculations. The rods will be supported approximately every 48 inches, using a fabricated idler arm assembly(see rudder). The calculations for this are shown directly below.

3.4.1 Structural Substantiation

$$\begin{array}{llll}
 f = P/A & f_{LL} = 1.2 \cdot f & f_{UL} = F.S. \cdot f_{LL} & M.S._{yield} = F_y/f_y - 1 \\
 = 2200/.616 & = 1.2 \cdot 11459 & = 2 \cdot 13751 & = 39000/13751 - 1 \\
 f = 11459 \text{ psi} & f_{LL} = 13751 \text{ psi} & f_{UL} = 27501 \text{ psi} & M.S._{ul} = F_{tu}/f_{tu} - 1 \\
 & & & = 56/27.5 - 1 \\
 & & & M.S._{ul} = 1.04 \\
 & & & M.S._{yield} = 1.84
 \end{array}$$

$$P_{crit} = \pi^2 \cdot E \cdot I / L^2 = \pi \cdot \pi \cdot (30E6) \cdot (.001766) / L^2 \rightarrow L = 48.6 \text{ in}$$

The push-pull rods transfer the displacement of the control column support to a bellcrank (see rudder) has dual universal joints on

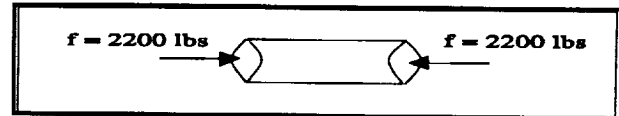


Figure 3.4.1

MS20271-B10 on either end which oscillate the elevator around two internal hinges. These U-Joints were selected according to the maximum torque that was calculated for the pivot point.

3.5 Elevator Trim

The elevator trim was conceptualized as a cable and pulley system attached to a jackscrew that controls the elevator trim deflection. The system is lightweight and is not used as frequently as the elevator, therefore the "feel" is not as important and using push-pull rods cannot be justified. According to the MIL Handbook, a pilot can only exert 59 lbs by gripping the trim wheel and turning it. It was then decided that in the interest of producibility, the trim system would use the same pulleys, sprockets and cable as the aileron system, which was designed for 160 lbs. This creates a factor of safety of approximately 4.0 for the elevator trim system. The trim wheel and indicator are located on the control panel in between the pilot's seats and can be rotated clockwise or counterclockwise which turns the cable and, producing motion in the jackscrew, which connects to a piano hinge to create a $\pm 10^\circ$ maximum deflection.

3.6 Manufacturing and Maintenance

The entire elevator control system was designed with maintainability and life cycle in mind. Access panels are located on the bottom portion of the fuselage and on the cowling to provide easy access to both the push-pull rods, the trim system and the control column support. . The stretch in the cable can be adjusted using the turnbuckles and cable joiners. The motion of the part and its use were kept in mind while selecting the proper material to withstand the stresses. The same part was used throughout the cockpit control system, ie the idler arms were used for both the rudder and elevator, to minimize the number of parts that have to be stocked or ordered. In conclusion, the elevator control system meets the requirements of the SOW for the Viper D-2, FAR Part 23 and MIL Handbook. The pin attachment was originally conceptualized as a cog wheel track with a locking pin but was changed to the pin idea presented in this report.

4.0 AILERON CONTROL SYSTEM

4.1 Description

The aileron control system provides aileron deflections of positive 20 degrees and negative 15 degrees. The system is operated by rotating the control yoke 90 degrees in either direction; clockwise for right roll and counter-clockwise for left. The cockpit portion of the system uses sprockets and chains to transfer yoke rotation to the lower portion of the control column. This is translated through cables which run through the driveshaft tunnel to a set of bellcranks which transfer displacement to the ailerons.

4.2 LOADS AND LOADING

The analysis of the "cockpit " portion of the aileron system will begin with the determination of the static loads created by the application of the forces which correspond to the maximum possible forces as prescribed by the federal aviation administration.(F.A.R 23.397) It will also be taken into consideration that the system has been preloaded to 115 percent of these F.A.R values prior to the current application of the forces. It should also be noted that these forces will be added to the system in a way as to simulate the worst possible condition that could occur in the flight environment.

4.2.1 The first of the two worst case scenario's includes both pilots turning their wheels inboard simultaneously at the prescribed torque. The resultant static loads are shown below. Remember each closed system is preloaded to 620 pounds.

Summing the forces at sprocket S1 to find the resultant force on the bolt.

$$T1=T2=81lb$$

$$T3=T4=1159lb$$

$$T5=T6=620lb$$

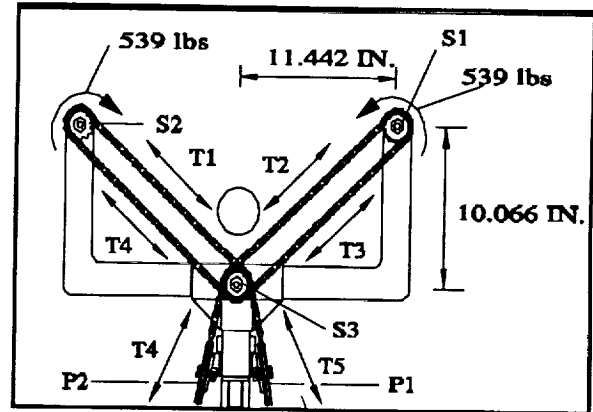


Figure 4.2.1

$$\Sigma F_{YS1} = -\cos(48.66) 81 - \cos(48.66) 1159$$

$$F_{RYS1} = 819.05 lb$$

$$\Sigma F_{XS1} = -\sin(48.66) 81 - \sin(48.66) 1159 + F_{RYS1}$$

$$F_{RXS1} = 931.0 lbs.$$

$$F_{RS1} = 1240.0 lb$$

By symmetry the resultant force on sprocket S2 is equal to S1

$$F_{RS2} = 1240.0 lbs.$$

Summing the forces at sprocket S3 to find the resultant force on the bolt.

$$\Sigma F_Y = (819) 2 - (570) 2 + F_{RYS3}$$

$$F_{RYS3} = F_{RS3} = 498 \text{ lb}$$

Summing the forces, in the plane parallel to the pulley, at pulley P5 to find the resultant force on the bolt.

$$\Sigma F_X = \cos 11.83 (620) + F_{RXP5}$$

$$F_{RXP5} = 606.83 \text{ lb}$$

$$\Sigma F_Y = 620 - \sin 11.83 (620) - F_{RYP5}$$

$$F_{RYP5} = -492.89 \text{ lb}$$

$$F_{RP5} = 781.78$$

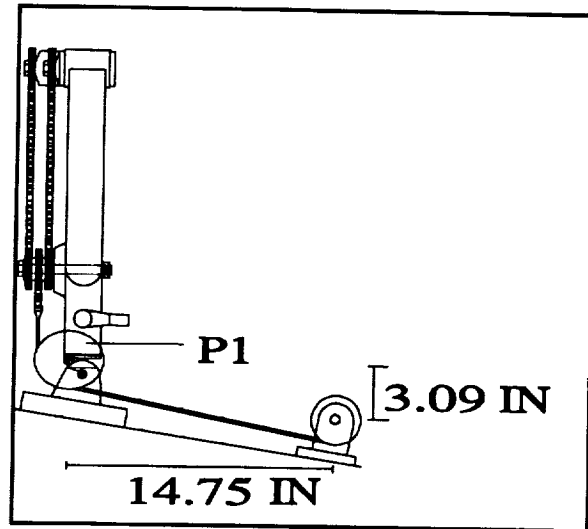


Figure 4.2.2

4.2.2 For the second worst case scenario the yoke wheels are both turned outward simultaneously with the same torque the values. In this case T1,T2,T3, and T4 will swap values but will result in identical resultant values on the bolts.

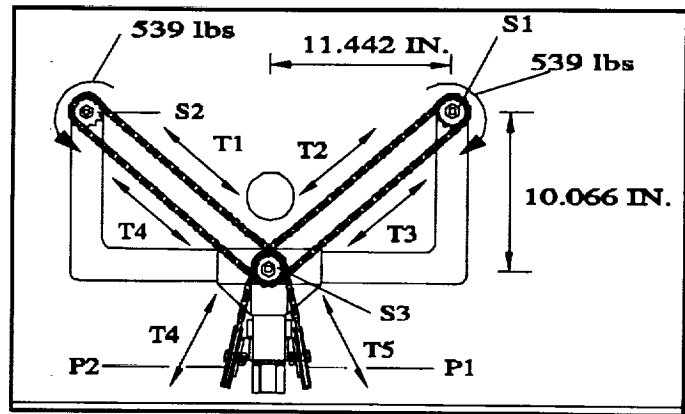


Figure 4.2.3

4.3 STRUCTURAL SUBSTANTIATION

Now that the system has been statically defined these values will be used to evaluate the structural fortitude of the members that are recipients of these loads. This will be done by evaluating the various stresses and the corresponding factor and margin of safety. It should be noted that all forces have been multiplied by a fitting factor of 1.5.

4.3.1 Sprockets 1 and 2.

$$f_{shear} = \frac{P}{A} = \frac{1860}{0.11} = 16909.09 \frac{lbs}{in.^2}$$

$$f_{br} = \frac{P}{td} = \frac{1860}{0.23(0.38)} = 21281.46 \frac{lbs.}{in.^2}$$

Due to bearing stress:

$$M.S._{L.L.} = 1.97, F.S._{L.L.} = 2.97, M.S._{U.L.} = 3.45, F.S._{U.L.} = 4.45$$

4.3.2 Sprocket assembly 3.

$$f_{shear} = \frac{P}{A} = \frac{498.1}{0.22} = 3396.00 \frac{lbs.}{in.^2}$$

$$f_{bearing} = \frac{P}{td} = \frac{498.1}{1.60(0.53)} = 585.17 \frac{lbs.}{in.^2}$$

Due to shear:

$$M.S._{L.L.} = 17.74, F.S._{L.L.} = 18.74, M.S._{U.L.} = 27.11, F.S._{U.L.} = 28.11$$

4.3.3 Pulleys 5 and 6

$$f_{shear} = \frac{P}{A} = \frac{1172.67}{0.09} = 13029.67 \frac{lbs.}{in.^2}$$

$$f_{bearing} = \frac{P}{td} = \frac{1172.67}{0.20(.341)} = 17194.57 \frac{lbs.}{in.^2}$$

Due to bearing:

$$M.S._{L.L.} = 3.70, F.S._{L.L.} = 2.70, M.S._{U.L.} = 4.55, F.S._{U.L.} = 5.55$$

4.4 Manufacturing and Maintenance

The aileron control system consists largely of aircraft approved, vendor supplied hardware; including all fasteners, fittings, chain, and cable. Manufactured components include the bellcranks and female jack-screw assembly which are cast from 355.0-T6 aluminum. The sprocket assemblies require welding which will be done in-house.

5.0 WEIGHT SUMMARY

COMPONENT	WEIGHT (lbs)
Rudder	
Pedals	4.1
Bellcranks	2.0
Brakes	3.0
Rods	4.4
Hardware	7.1
Elevator	
Adjustable Control Yoke Assembly	2.9
Control Column Support Assembly	3.1
Push-Pull Rods	4.2
Trim	3.2
Allerons	
Chains	3.1
Sprockets	.49
Pulleys	.9
Cable	6.0
Bellcrank	4.0
TOTAL	47.8

6.0 CONCLUSION

The goal of this design project was to provide a simple yet effective cockpit control system, meeting FAR specifications and designed with human comfort in mind. It has been shown that his design meets the above listed criteria, but their is always room for improvement. Several components have been designed with excessive margins of safety, and weight reduction is possible by removing excess material.

APPENDIX

Design substantiation was done for all cockpit control system components. Analysis consisted of Margin of Safety calculations for the limit load and ultimate loading cases. Fitting factors were applied to both rotating and non-rotating joints. It should also be noted that a stress concentration factor of 3.0 was applied to the pedal actuated crank in bending. The following equations were used in the substation analysis.

$$f_{bearing} = \frac{P}{td} \times F.F.$$

$$f_{t.o.} = \frac{P}{2Xt} \times F.F.$$

$$f_{tens} = \frac{P}{(h-d)t} \times F.F.$$

$$f_{shear} = \frac{P}{A} \times F.F.$$

$$f_{comp.} = \frac{P}{A}$$

$$f_{crit. axial} = \frac{\pi^2 EI}{Al^2}$$

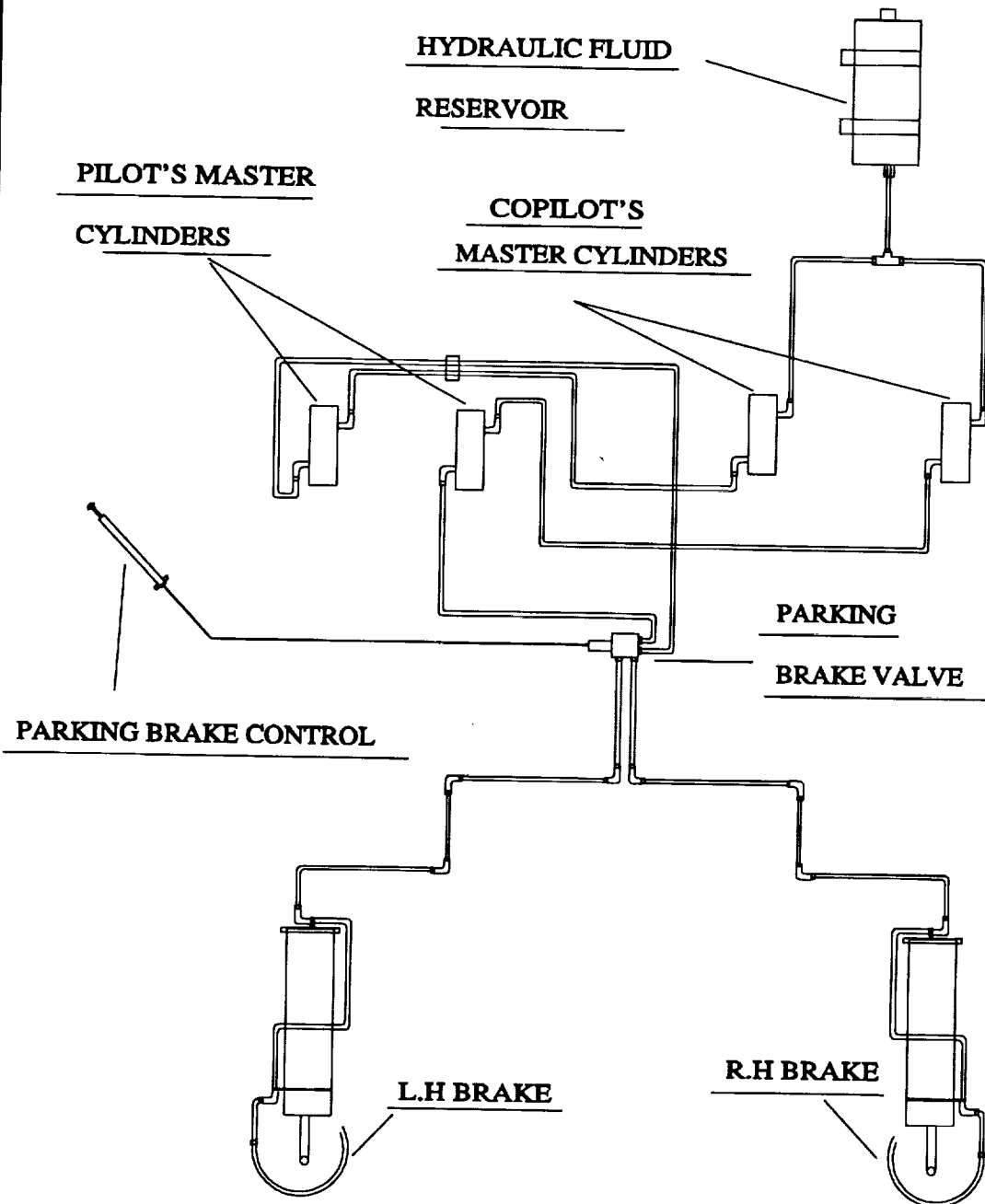
$$F.F._{rotating} = 2.0$$

$$F.F._{non-rotating} = 1.2$$

$$M.S._{L.L.} = \frac{F_{yield}}{f_{L.L.}} - 1$$

$$M.S._{ULT} = \frac{F_{ULT}}{f_{L.L.} 1.5} - 1$$

BRAKE SYSTEM

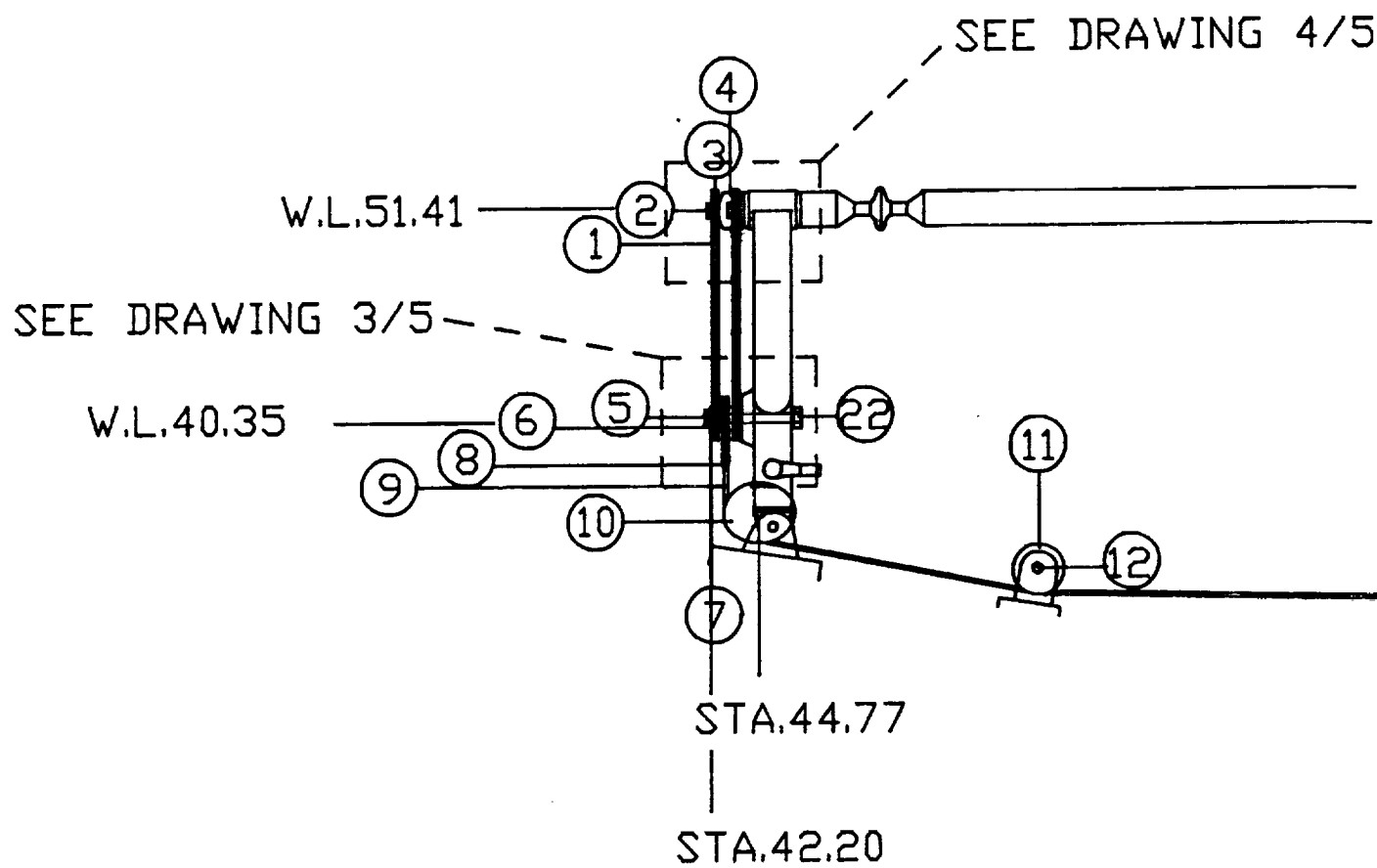


22	1	NUT	421S9303D
21	26	NUT	AN315-4
20	12	BOLT	AN4-24
19	4	BOLT	NAS1304-17
18	2	BOLT	NAS1304-15
17	2	JACKSCREW	421S9303D

	16	2	ROD BEARING AND FEMALE JACK	421S9303D188
	15	2	HORN ASSEMBLY	421S9303D186
	14	4	TERMINAL	MS20667-5
	13	2	BELL CRANK	421S9303D184
	12	8	BOLT	NAS1305-1
	11	8	PULLEY	AN221-1
	10	2	INNER DIA. STEELPULLEY	421S9303D182
	09	680IN	3/16 FLEXIBLE STEELCABLE	MIL-C-5424
	08	2	CABLE, CHAIN UNION	421S9303D180
	07	1	TRIPLE SPROCKET ASSEMBLY	421S9303D178
	06	1	BEARING	421S9303D176
	05	1	.532IN DIA. 4.883IN LEN. STEEL	421S9303D174
	04	2	SPROCKET SUPPORT BRACKET	421S9303D172
	03	5	0.500 PITCH SPROCKET	41EM-B-12
	02	2	..379IN DIA. 1.00IN LEN. STEEL	421S9303D170
	01	60IN	0.500 PITCH CHAIN	RC4155
92	ITEM	QTY	DESCRIPTION	PART #

90	DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL		EMBRY-RIDDLE AERONAUTICAL UNIVERSITY			
			DAYTONA BEACH FLORIDA			
	.XX ± .01		SIZE	DATE	SCALE	DRAWN BY
	.XXX ± .001		B	3/14	1/20	G. SCHNEIDER
	ANGULAR ± 1/2°		TITLE			
			AILERON CONTROL SYSTEM			
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			421S9303D166			1/5

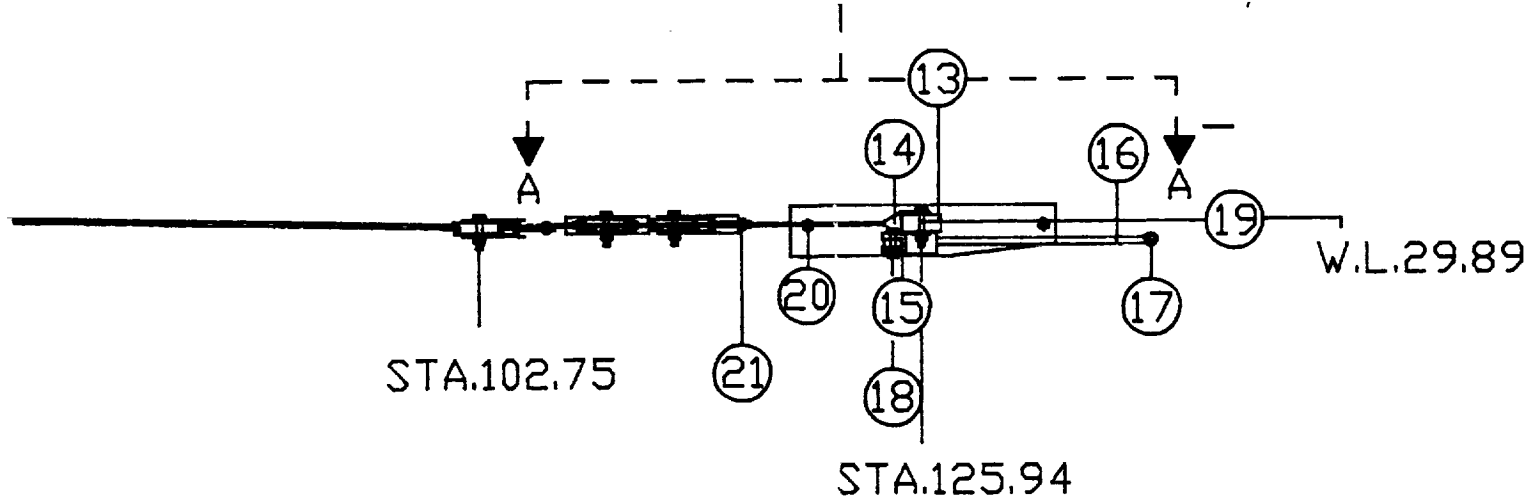
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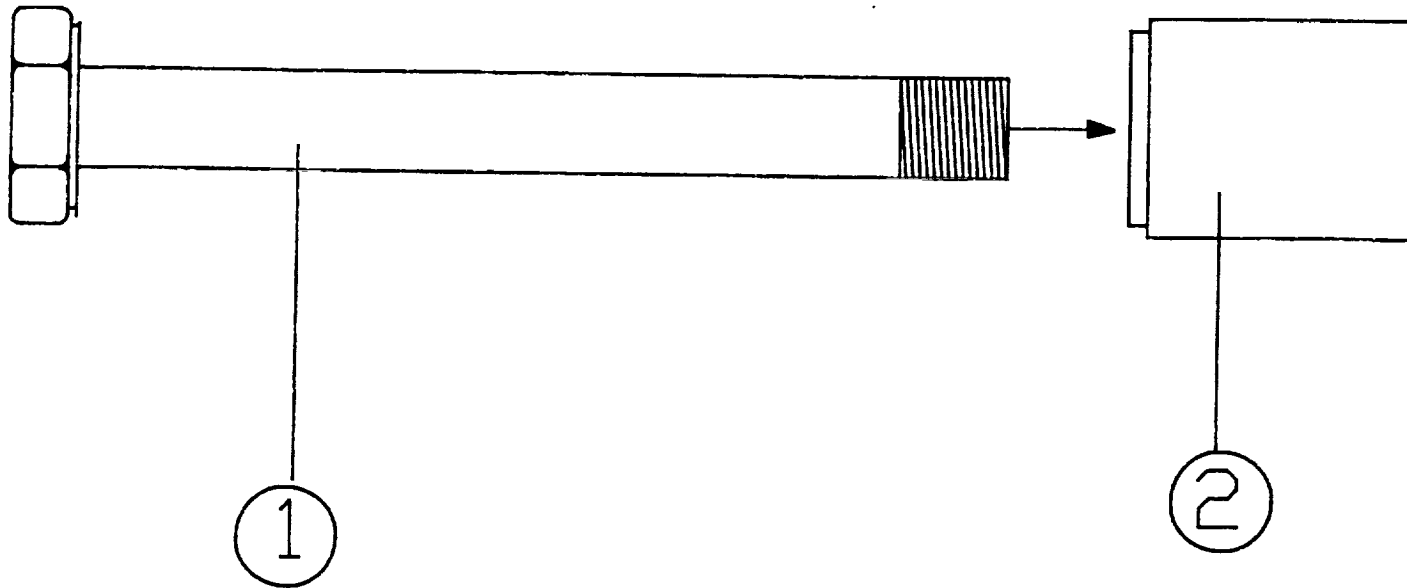
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SEE DRAWING 5/5

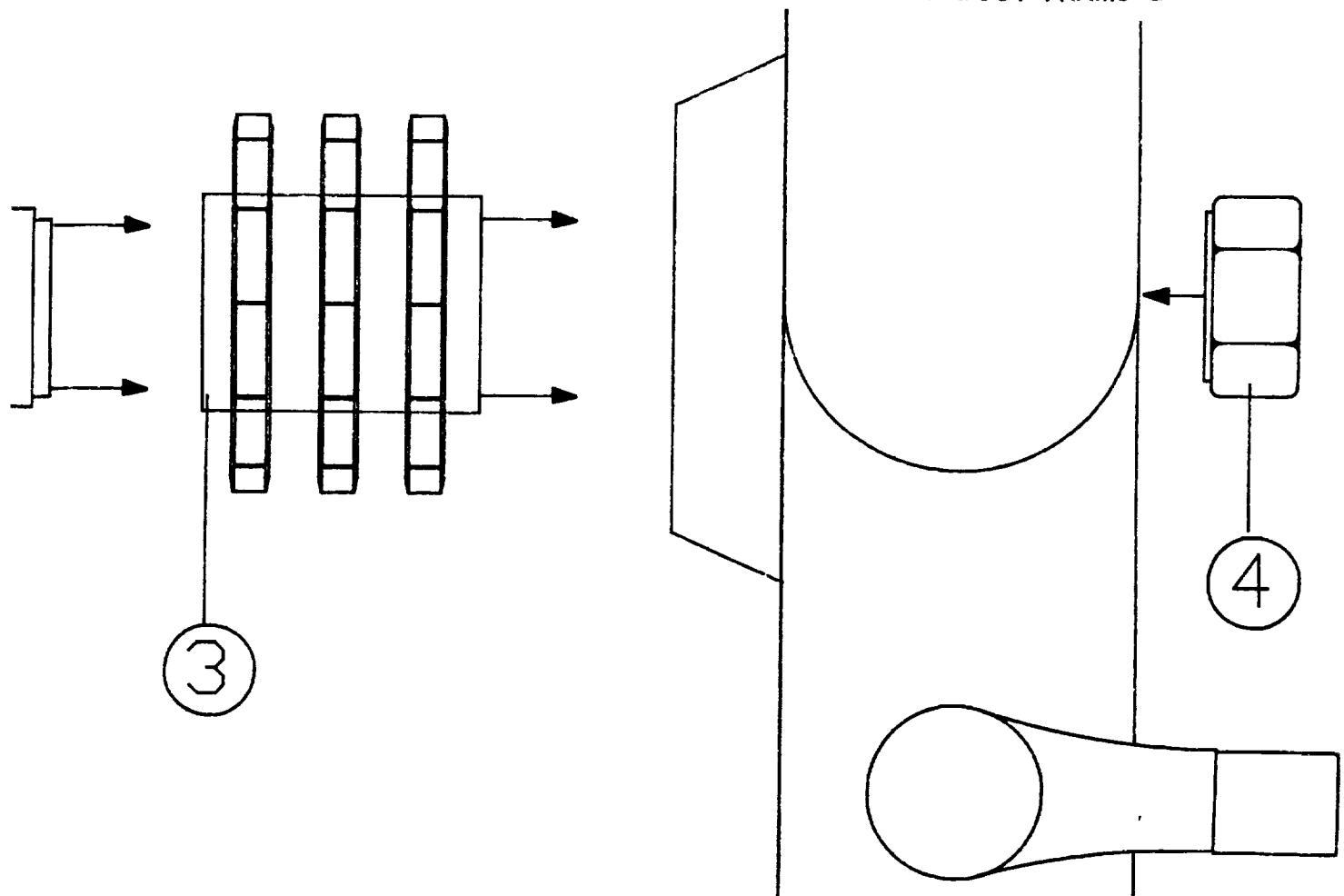


DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL .XX ± .01 .XXX ± .001 ANGULAR ± 1/2°	EMBRY-RIDDLE AERONAUTICAL UNIVERSITY DAYTONA BEACH FLORIDA			
	SIZE	DATE	SCALE	DRAWN BY
	B	3/14/93	1/10	G. SCHNEIDER
	TITLE			
	AILERON CONTROL SYSTEM			
	DRAWING NO.			SHEET
	421S9303D166			2/5

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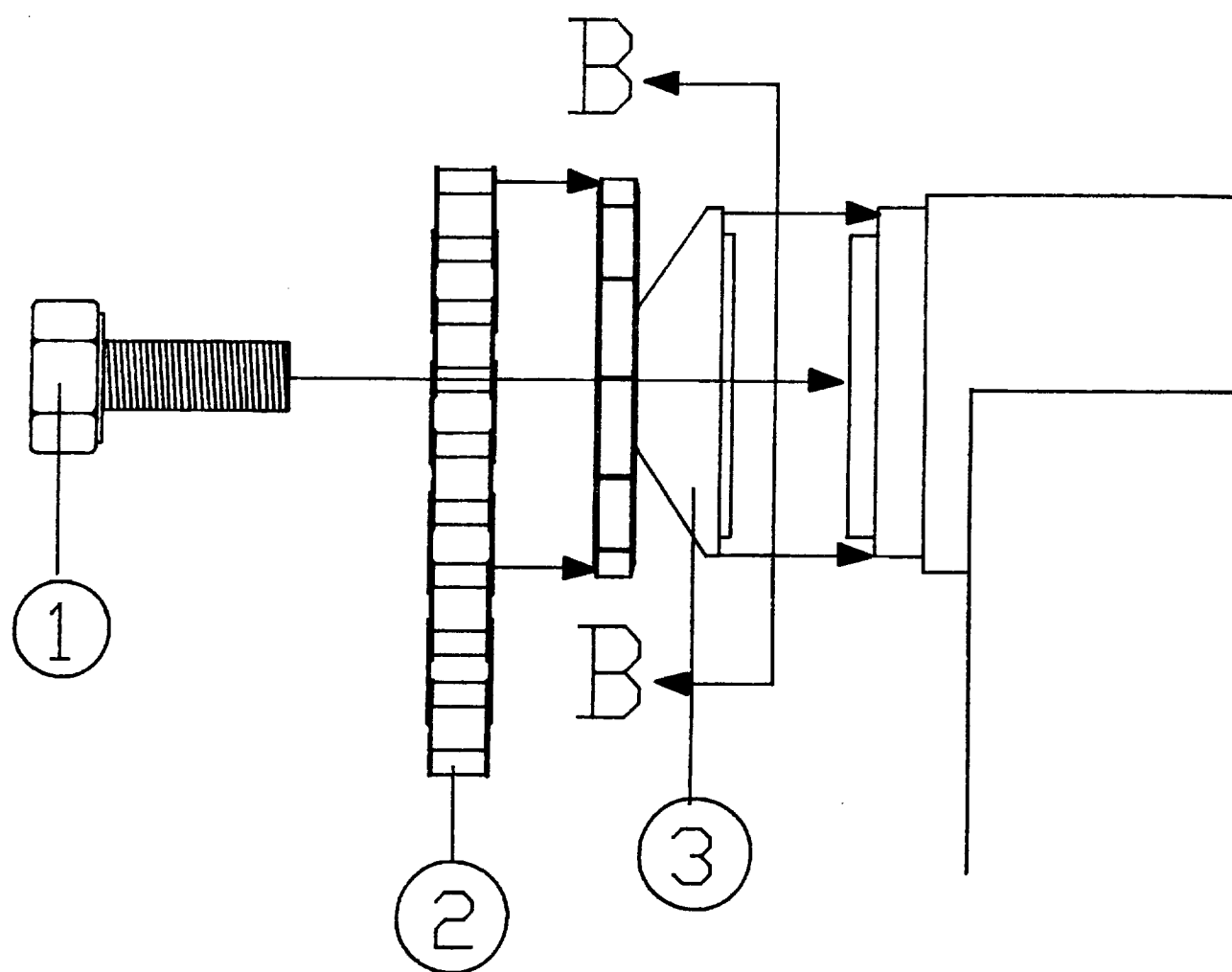


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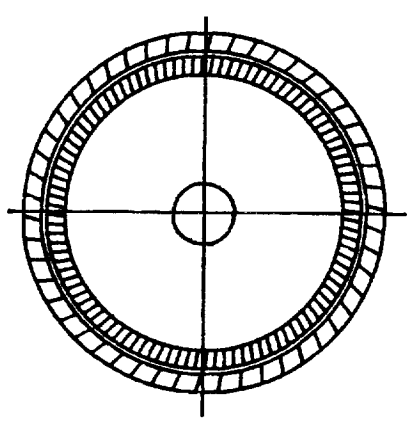


4	1	NUT	421S9303D19												
3	1	TRIPLE SPROK.	421S9303D178												
2	2	BEARING	421S9303D176												
1	1	.532IN DIA.	421S9303D174												
ITEM	QTY	DESCRIPTION	PART#												
DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL .XX ± .01 .XXX ± .001 ANGULAR ± 1/2° EMBRY-RIDDLE AERONAUTICAL UNIVERSITY DAYTONA BEACH FLORIDA <table> <tr> <td>SIZE B</td><td>DATE 3/14</td><td>SCALE 1/1</td><td>DRAWN BY G.SCHNEIDER</td></tr> <tr> <td colspan="4">TITLE AILERON CONTROL SYSTEM</td></tr> <tr> <td colspan="3">DRAWING NO. 421S9303D166</td><td>SHEET 3/5</td></tr> </table>				SIZE B	DATE 3/14	SCALE 1/1	DRAWN BY G.SCHNEIDER	TITLE AILERON CONTROL SYSTEM				DRAWING NO. 421S9303D166			SHEET 3/5
SIZE B	DATE 3/14	SCALE 1/1	DRAWN BY G.SCHNEIDER												
TITLE AILERON CONTROL SYSTEM															
DRAWING NO. 421S9303D166			SHEET 3/5												

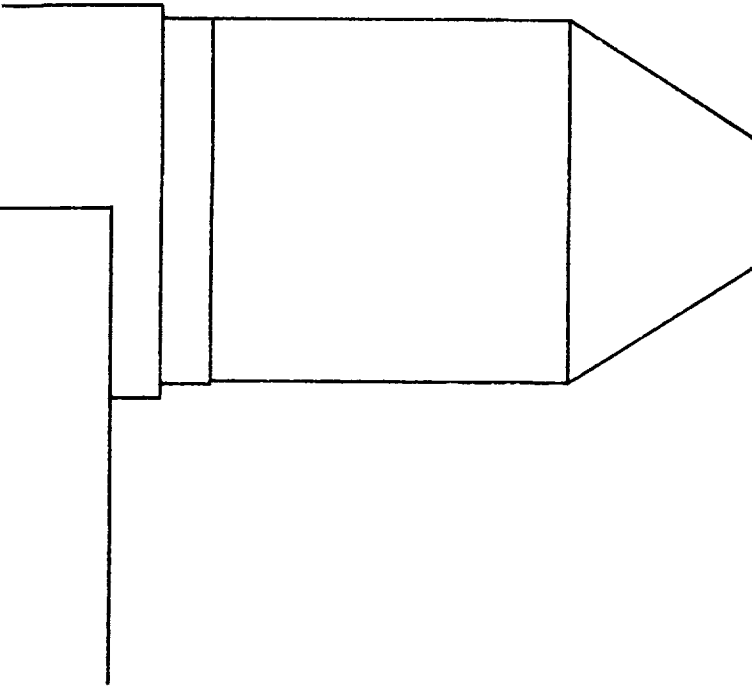
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B - B



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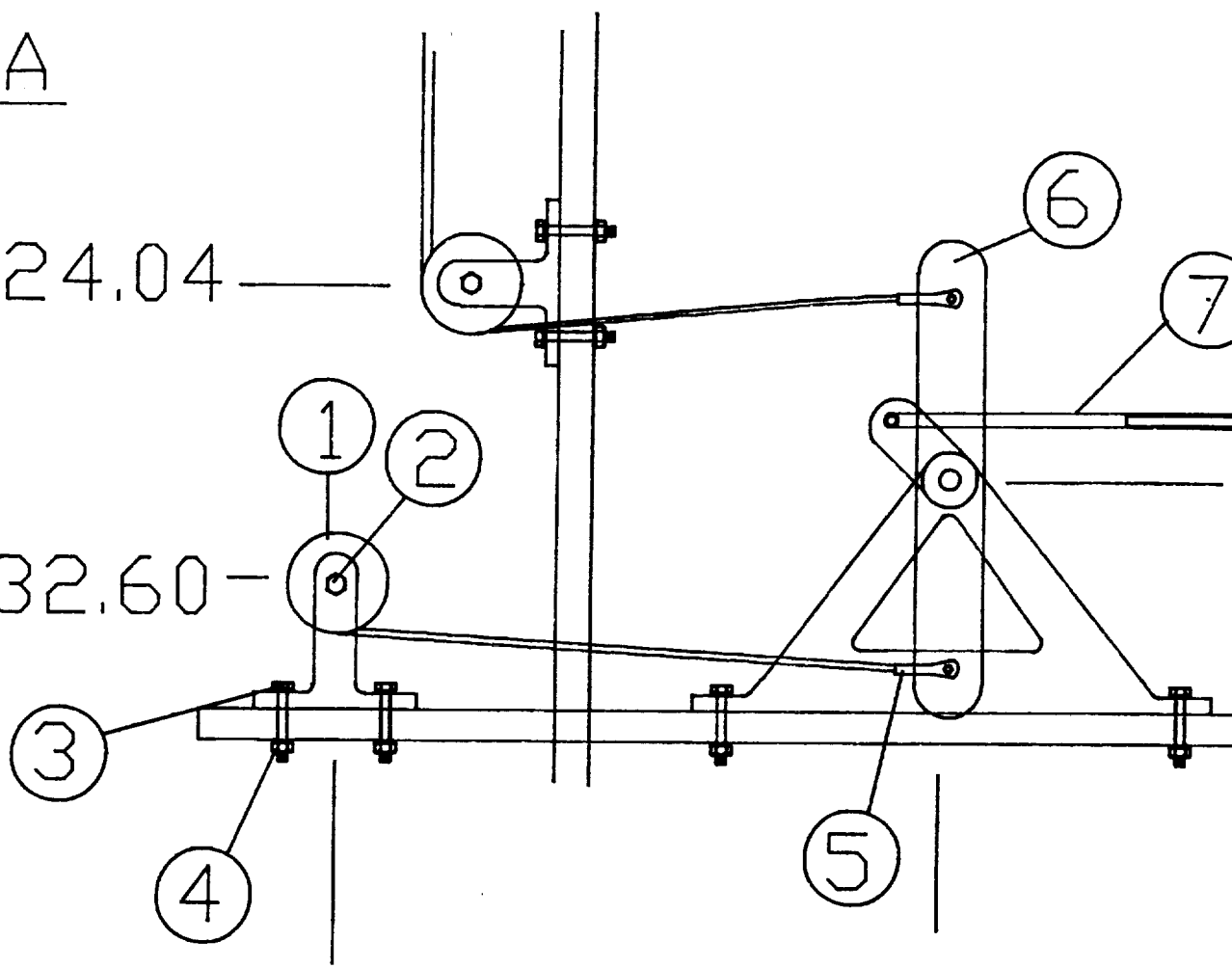


3	2	SPROCKET SUPP.	421S9303D172
2	60IN	0.50 PITCH CHN.	RC4155
1	2	.379IN DIA.	421S9303D170
ITEM	QTY	DESCRIPTION	PART#
DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL .XX ± .01 .XXX ± .001 ANGULAR ± 1/2°		EMBRY-RIDDLE AERONAUTICAL UNIVERSITY DAYTONA BEACH FLORIDA	
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		SCALE	DRAWN BY
		1/1	G.SCHNEIDER
		TITLE	
		AILERON CONTROL SYSTEM	
		DRAWING NO.	
		421S9303D166	SHEET
			4/5

A-A

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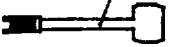
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STA.109.52

STA.125.9

8



B.L.129.75

4

8	2	JACKSCREW	421S9303D190
7	2	ROD BEARING,FEMALE J.	421S9303D188
6	2	BELL CRANK	421S9303D184
5	2	TERMINAL	MS20667-5
4	26	NUT	AN315-4
3	12	BOLT	AN4-24
2	8	BOLT	NAS1305-1
1	8	PULLEY	AN221-1
ITEM	QTY	DESCRIPTION	PART#

DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL .XX ± .01 .XXX ± .001 ANGULAR ± 1/2°		EMBRY-RIDDLE AERONAUTICAL UNIVERSITY DAYTONA BEACH FLORIDA			
		SIZE	DATE	SCALE	DRAWN BY
		B	3/14	1/10	G. SCHNEIDER
		TITLE			
		AILERON CONTROL SYSTEM			
		DRAWING NO.			SHEET
		421S9303D166			5/5

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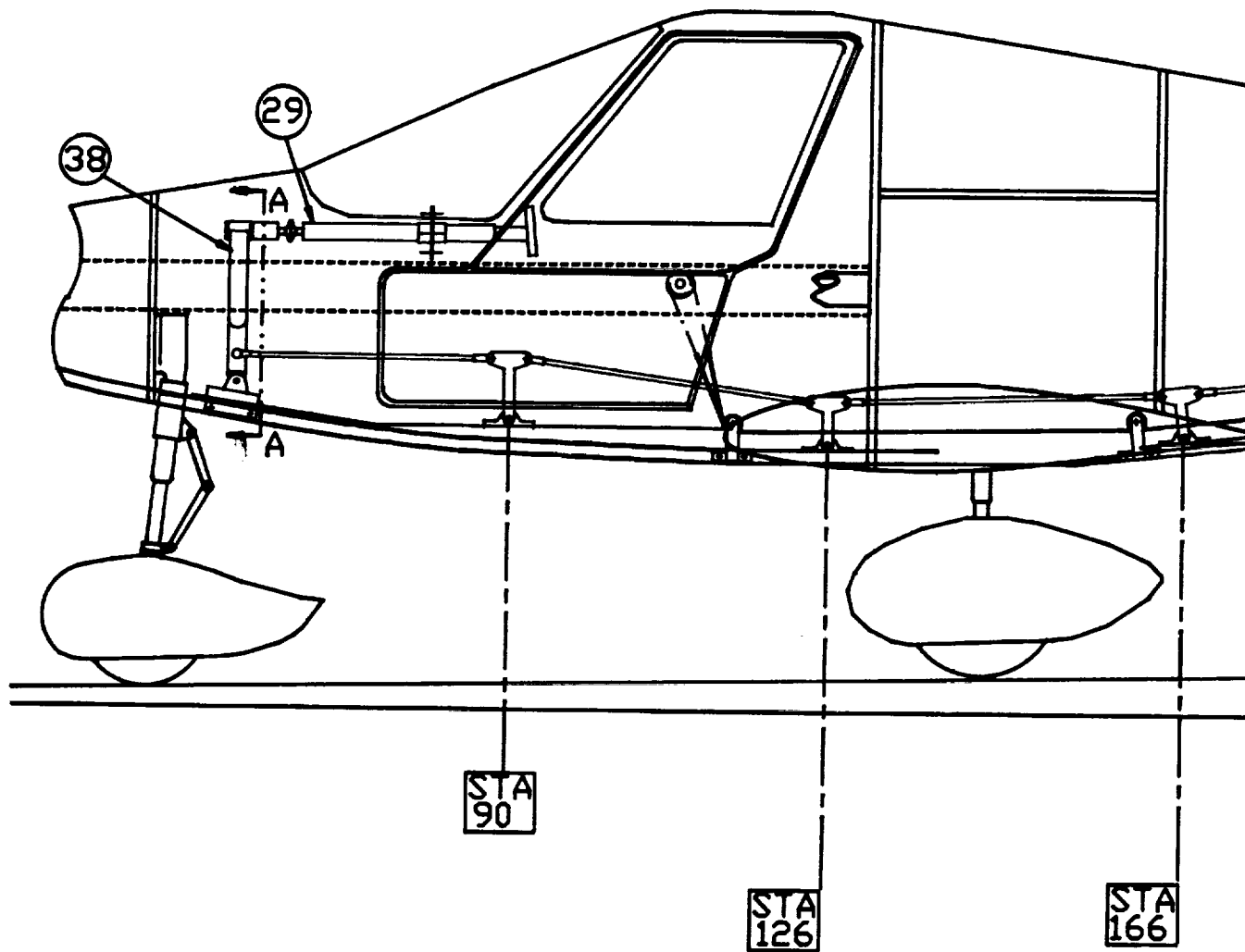
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37	2	PIANO HINGE	MS20
36	1	COLUMN ATTACHMENT	ALUM
35	2	HINGE 2	MS20
34	2	CONTROL COLUMN TOP	ALUM
33	12	NUTS	AN
32	12	WASHERS	AN
31	2	INNER YOLK SHAFT	ALU
30	12	YOLKE SCREWS	BS
29	2	YOLK ASSEMBLY	
28	1	TRIM PUSH ROD	ALL
27	1	SPROCKET 2	
26	8	BOLTS	AN4
25	1	ELEVATOR LEVER	ALUM
24	1	ACTUATOR	1260
23	2	ELEVATOR HINGE	MS2
22	1	BELLCRANK ASSEMBLY	421S
21	8	PULLEY	AN21
20	1	TURNBUCKLE	MS0
19	3	CABLE	MIL-
18	2	CHAIN .25 PITCH	RC25

2.

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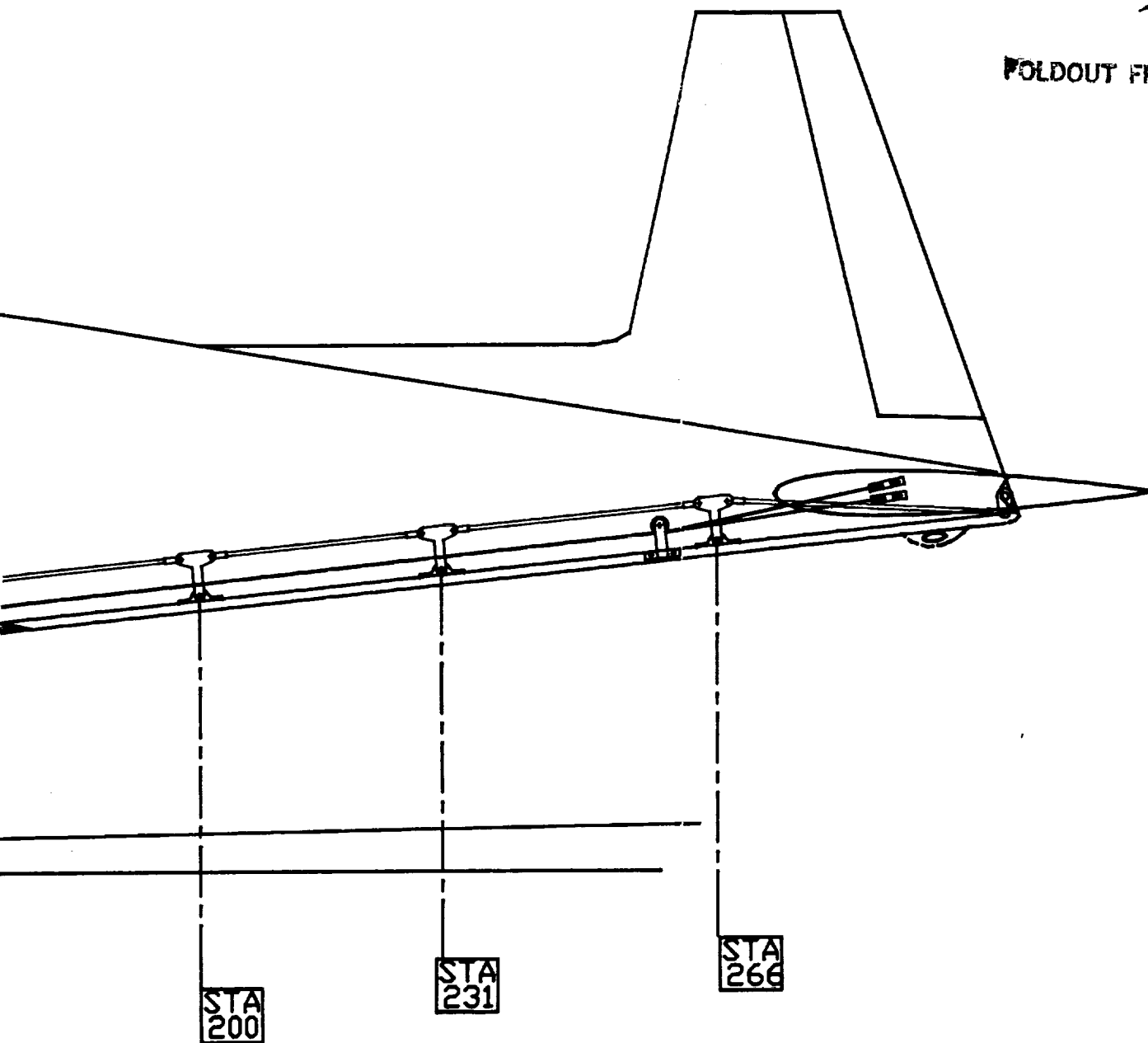
	17	2	BUSHING	0713032-1
	16	2	SPROCKET	25SP175-54
	15	1	TRIM WHEEL	0713656-1
	14	6	IDLER ARM ASSEMBLY	421S93D10306
	13	6	PUSH PULL RODS; 4130 STEEL	.5=D, .04=T
257P2800	12	1	PUSH PULL ROD ENDS	NAS-660R411
2219	11	1	CONTROL COLUMN ATTACHMENT PLATE	ALUM 2219
257-P2	10	1	CONTROL COLUMN JOINER	ALUM 2219
2219	9	1	CONTROL COLUMN SUPPRT SHAFT	ALUM 2219
310-C4	8	1	CONTROL COLUMN U-BAR	AMS-4162
60-1/4	7	2	NEEDLE-THRUST POINT BALL BEARING	NKX30/DUST
M 2219	6	4	UNIVERSAL JOINT	MS20271-B10
-0420-1	5	1	COLLAR	0713032-2
	4	2	YOLK SHAFT FASTENER	5610-401-20B
	2	2	ADJ. YOLK SHAFT	ALUM 2219
M 2219	3	2	OUTER YOLK SHAFT	ALUM 2219
	1	2	YOKE	PIN05-16610
	ITEM	QTY	DESCRIPTION	MAT/PART #
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0257-P2			SIZE	DATE
93D10306			B	3-15-93
0-313			SCALE	DRAWN BY
667-2			LISA COMBS	
C-5424A			TITLE	
SS-40			ELEVATOR INSTALLATION	
			DRAWING NO.	SHEET
			421S9303D101	1 OF 4

1 -
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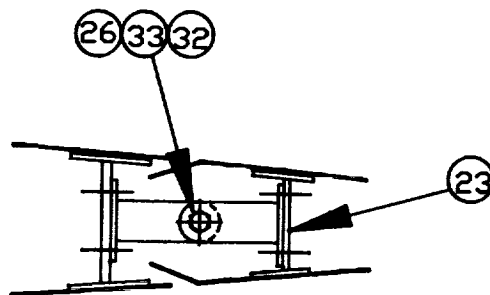
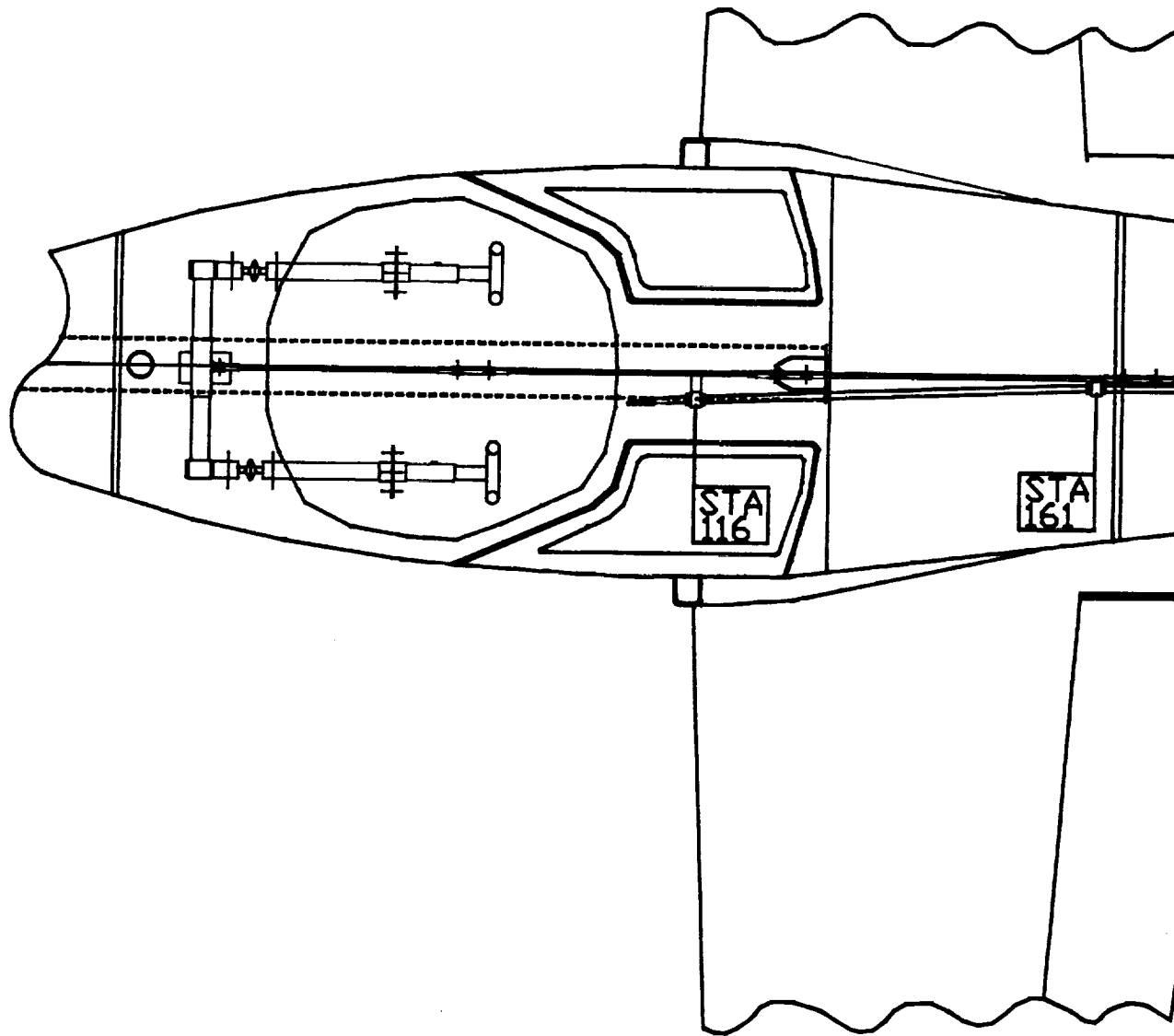
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.XX ± .01	SIZE	DATE	SCALE	DRAWN BY
.XXX ± .001	B	3-15-93	1/20	DAVID PAUFLER
ANGULAR ± 1/2°	TITLE			
	ELEVATOR INSTALLATION			
	DRAWING NO.			SHEET
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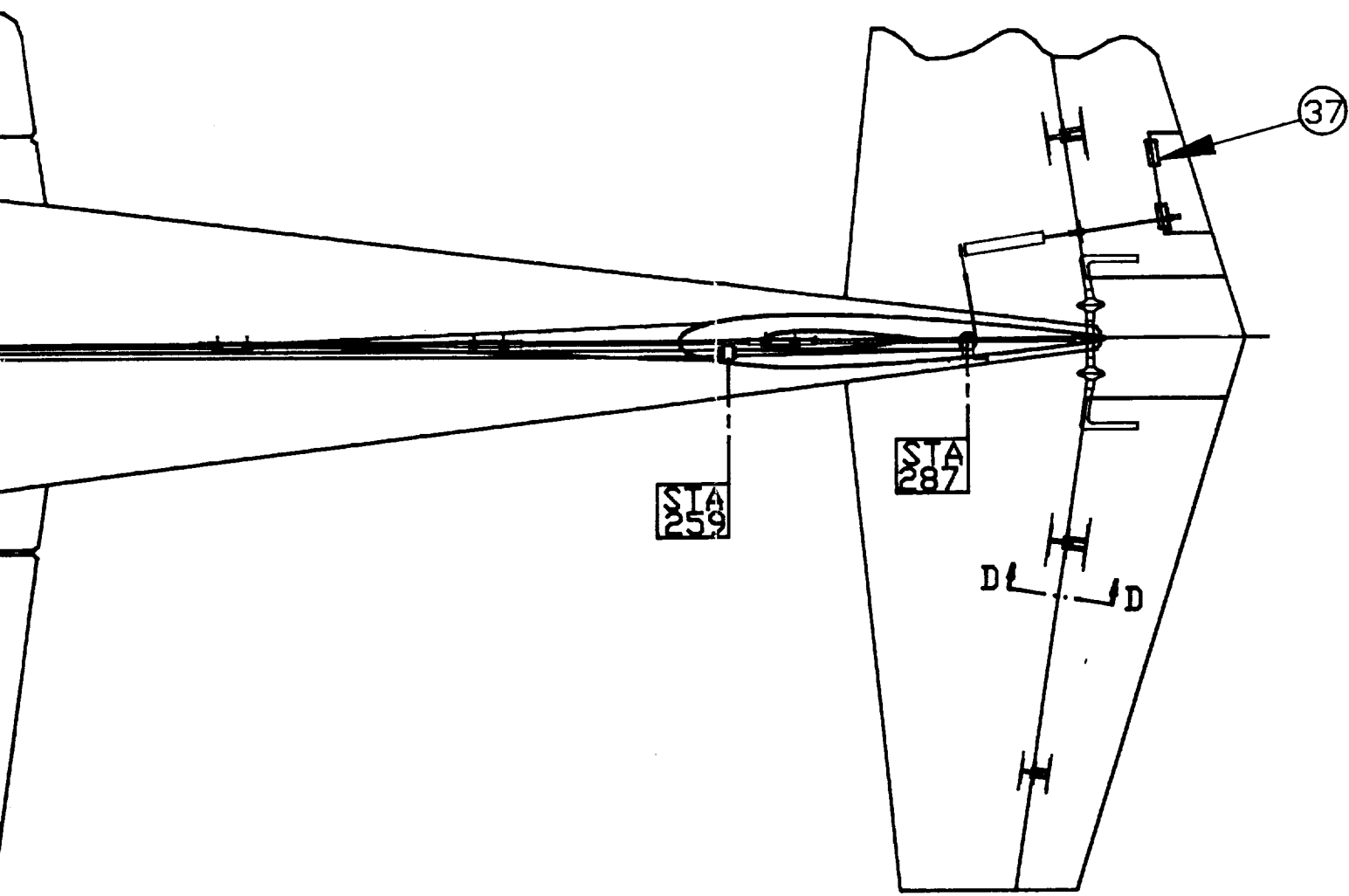
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SECTION D-D
1/5 SCALE

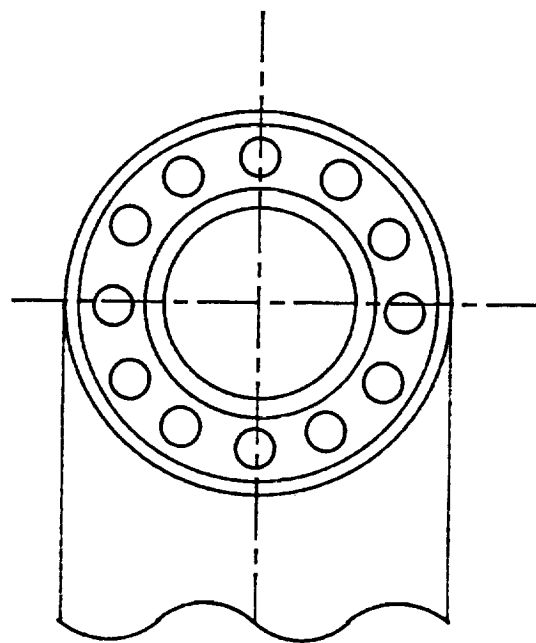
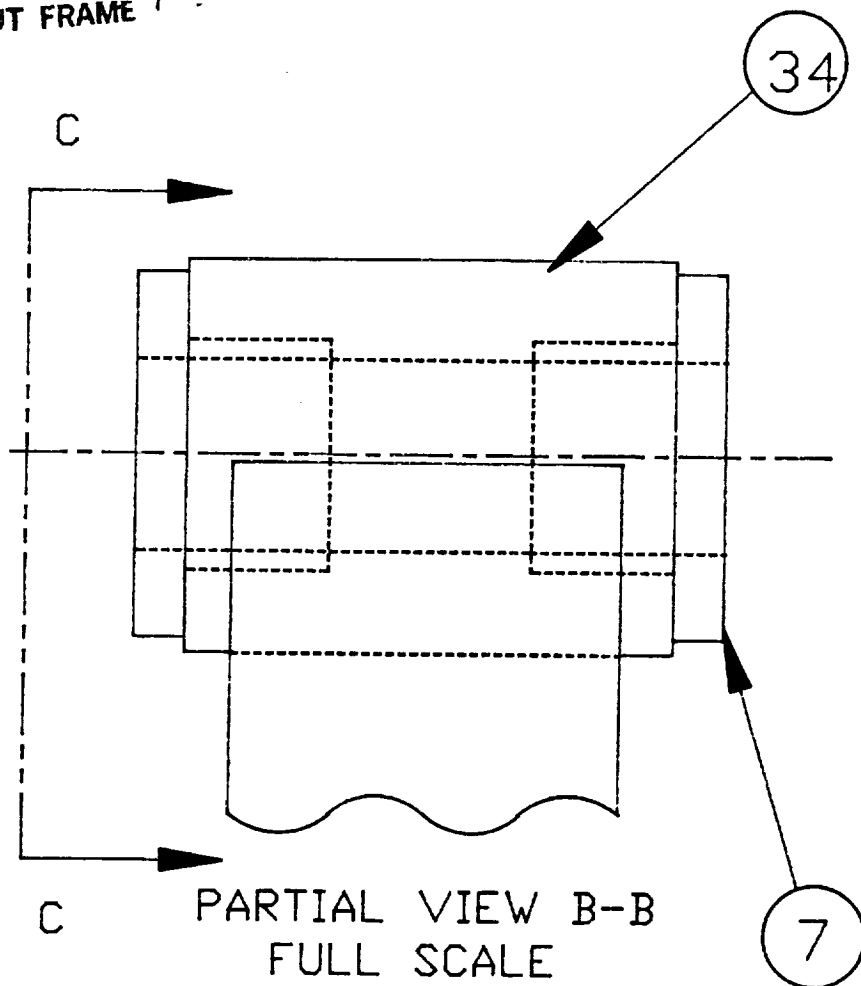
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.XX ± .01	SIZE	DATE	SCALE	DRAWN BY	
.XXX ± .001	B	3-15-93	1/20	DAVID PAUFLER	
TITLE		ELEVATOR INSTALLATION			
MILLAR		DRAWING NO.			SHEET
± 1/2°		421S9303D101			30F 4

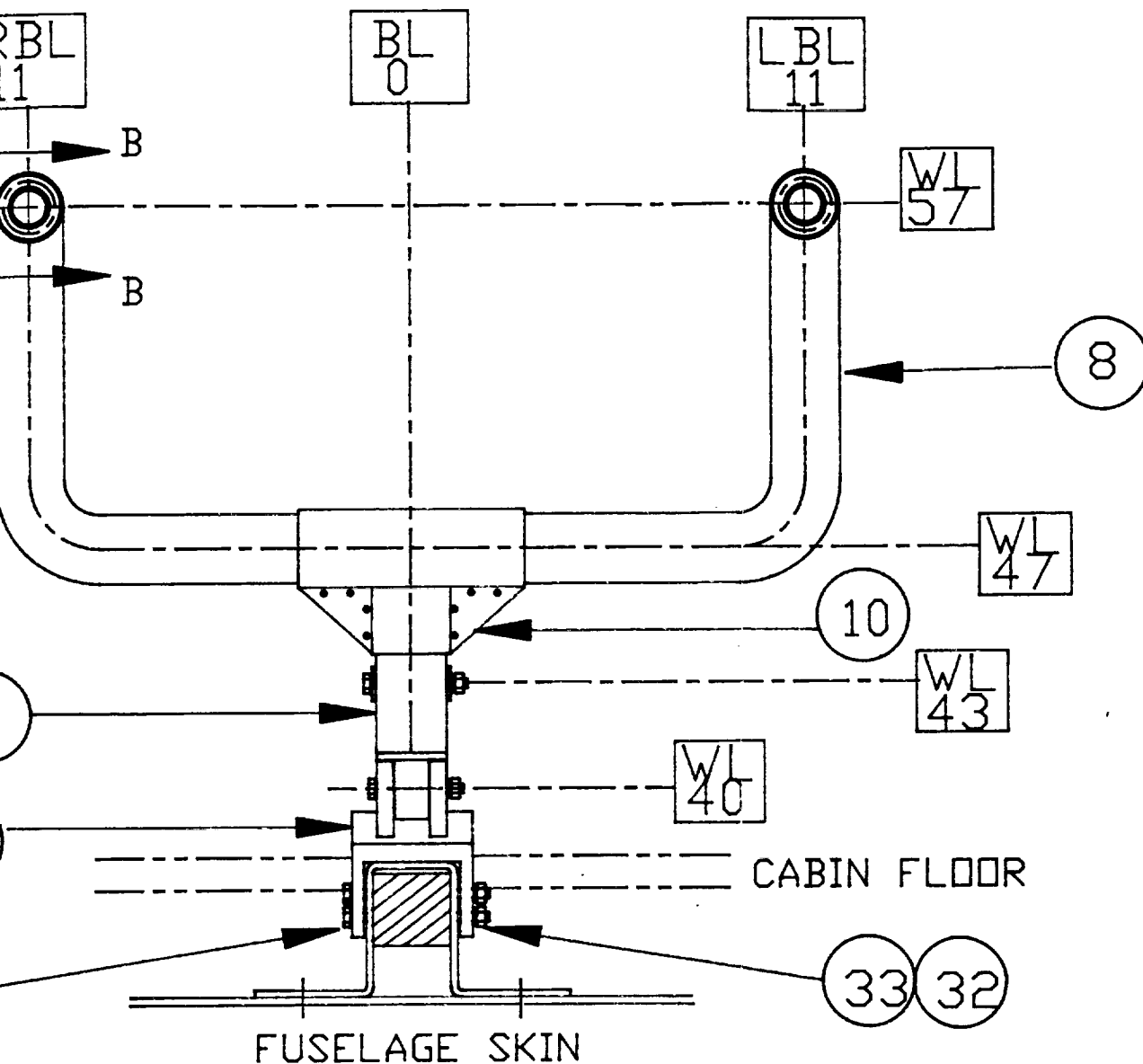
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PARTIAL VIEW C-C

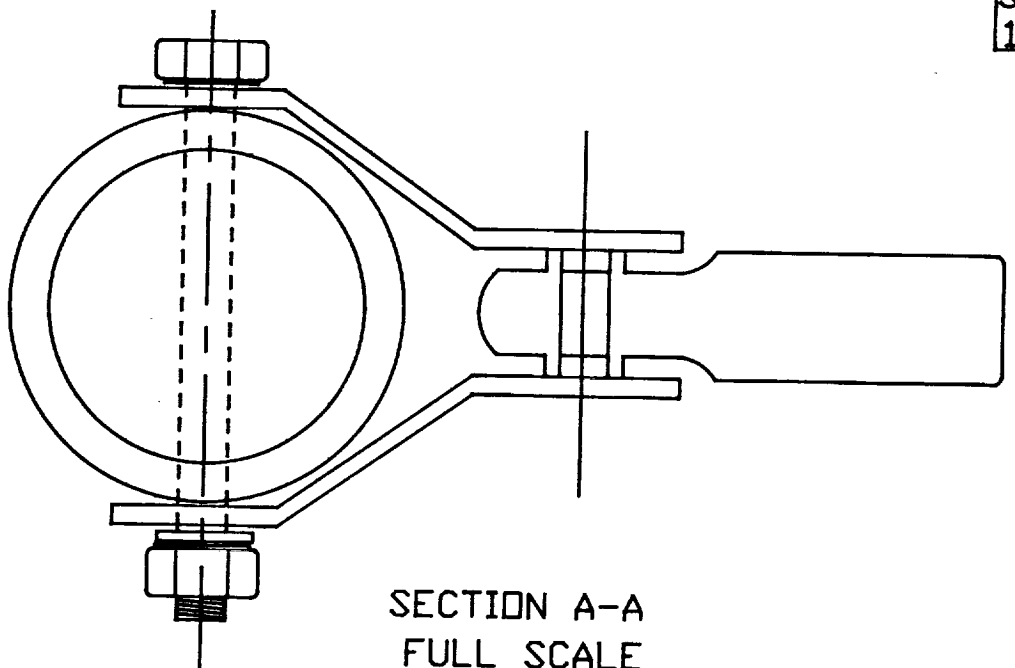
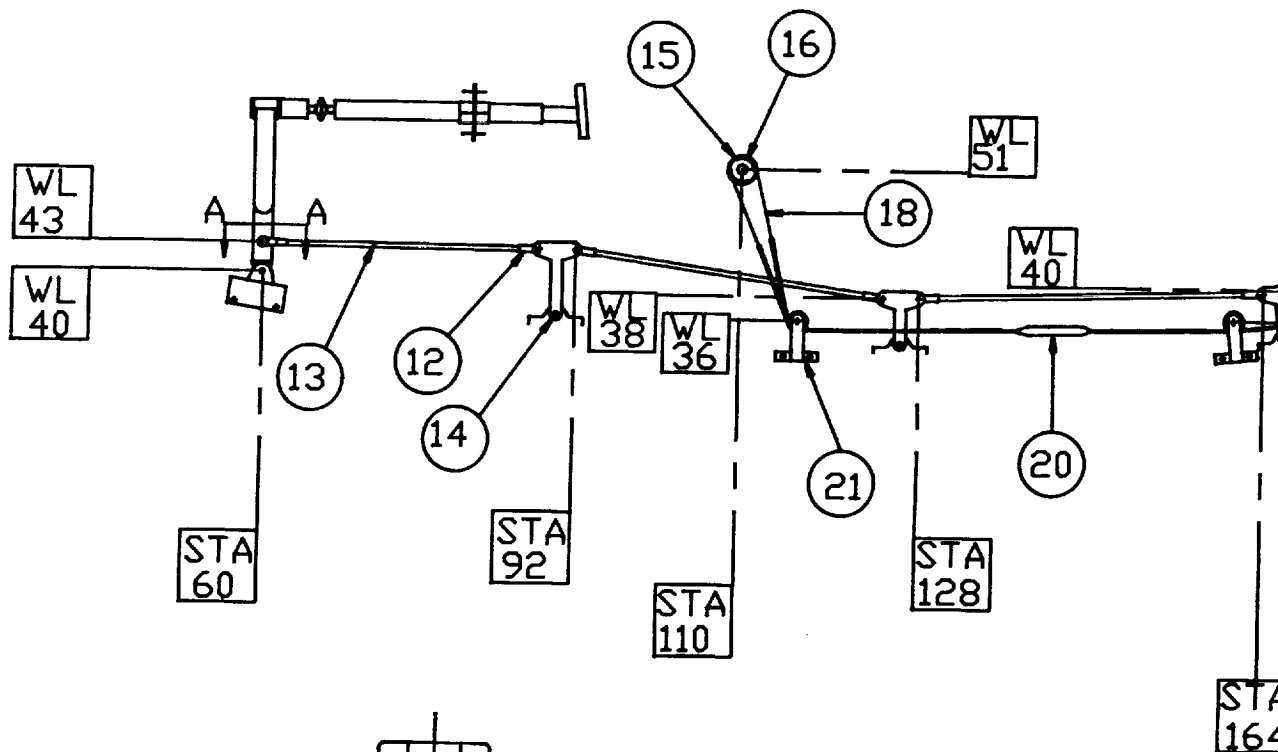
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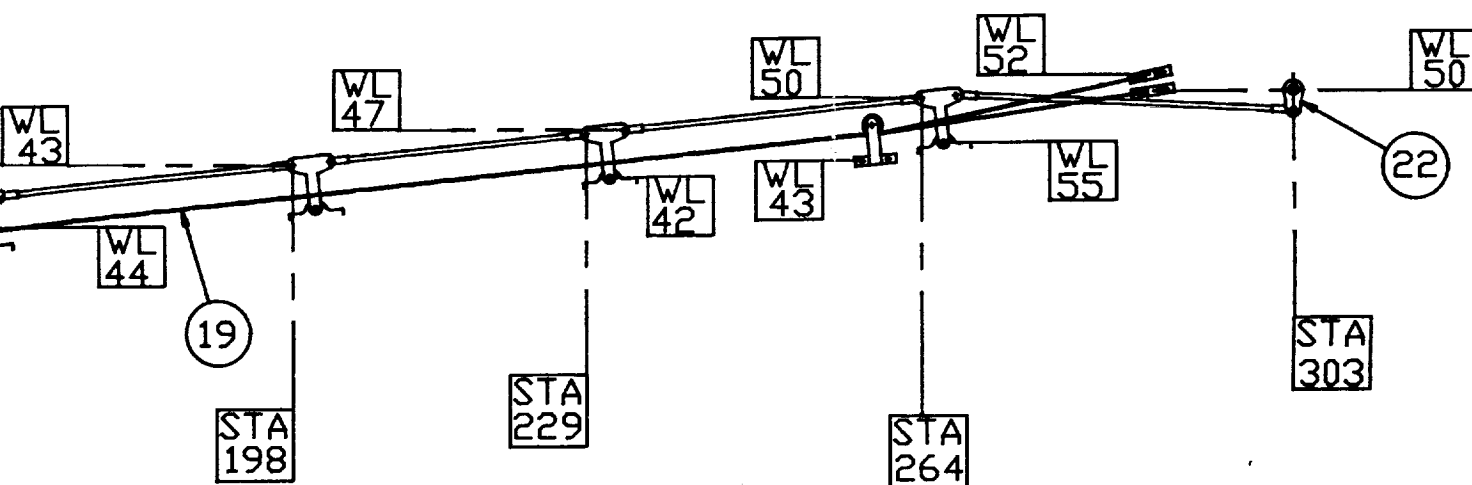
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.XXX ± .001	B	3-15-93	1/5	DAVID PAUFLER	
ANGULAR		TITLE			
± 1/2°	ELEVATOR INSTALLATION				
DRAWING NO.				SHEET	
421S9303D101				4 OF 4	

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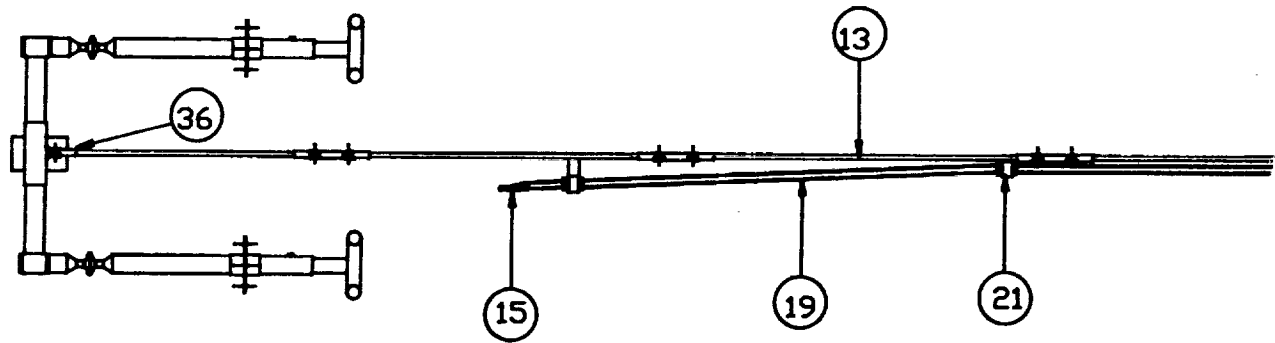
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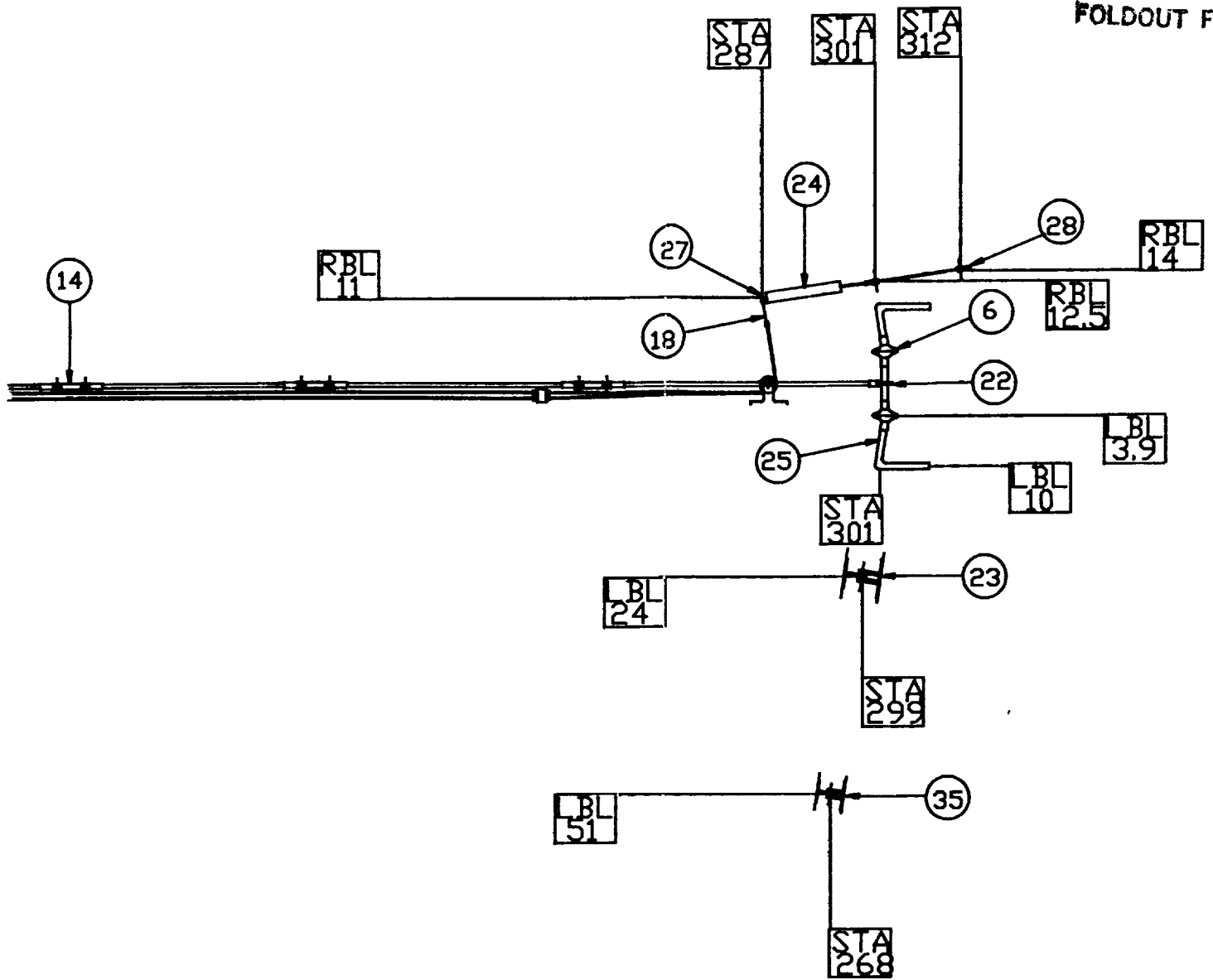


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.XXX ± .001	B	3-15-93	1/20	DAVID PAUFLER
ANGULAR ± 1/2°	TITLE			
	ELEVATOR SYSTEM ASSEMBLY			
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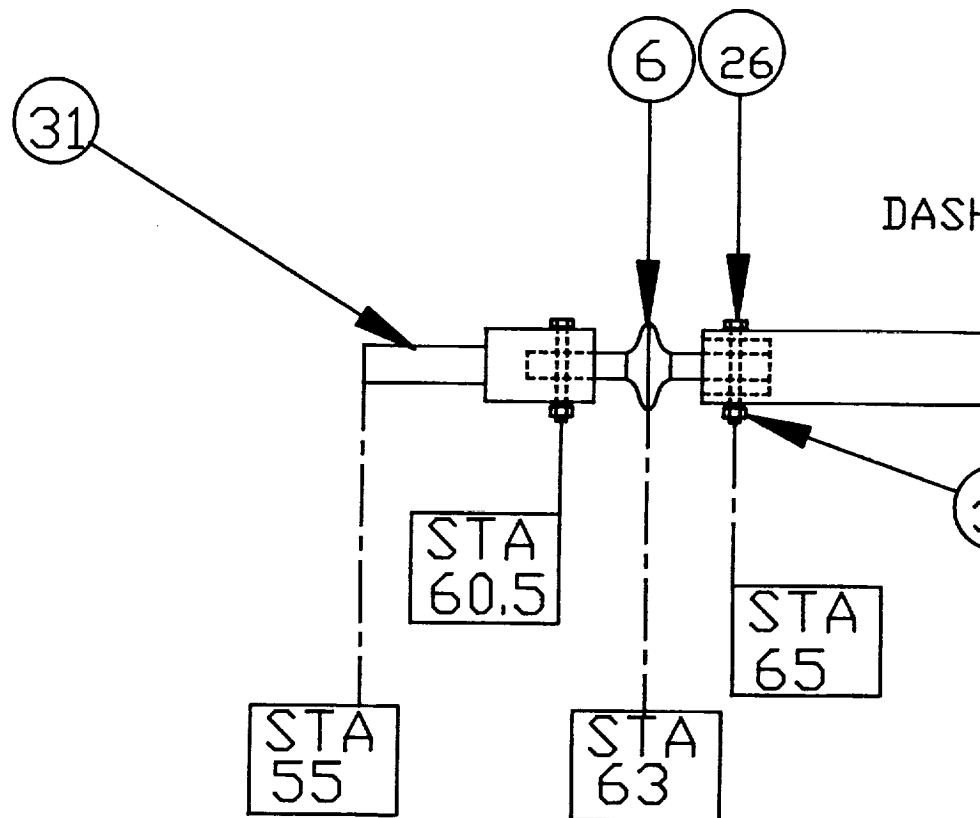


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.XXX ± .001	B	3-15-93	1/5	DAVID PAUFLER	
ANGULAR		TITLE			
± 1/2°		ELEVATOR SYSTEM ASSEMBLY			
DRAWING NO.				SHEET	
421S9303D103				20F2	

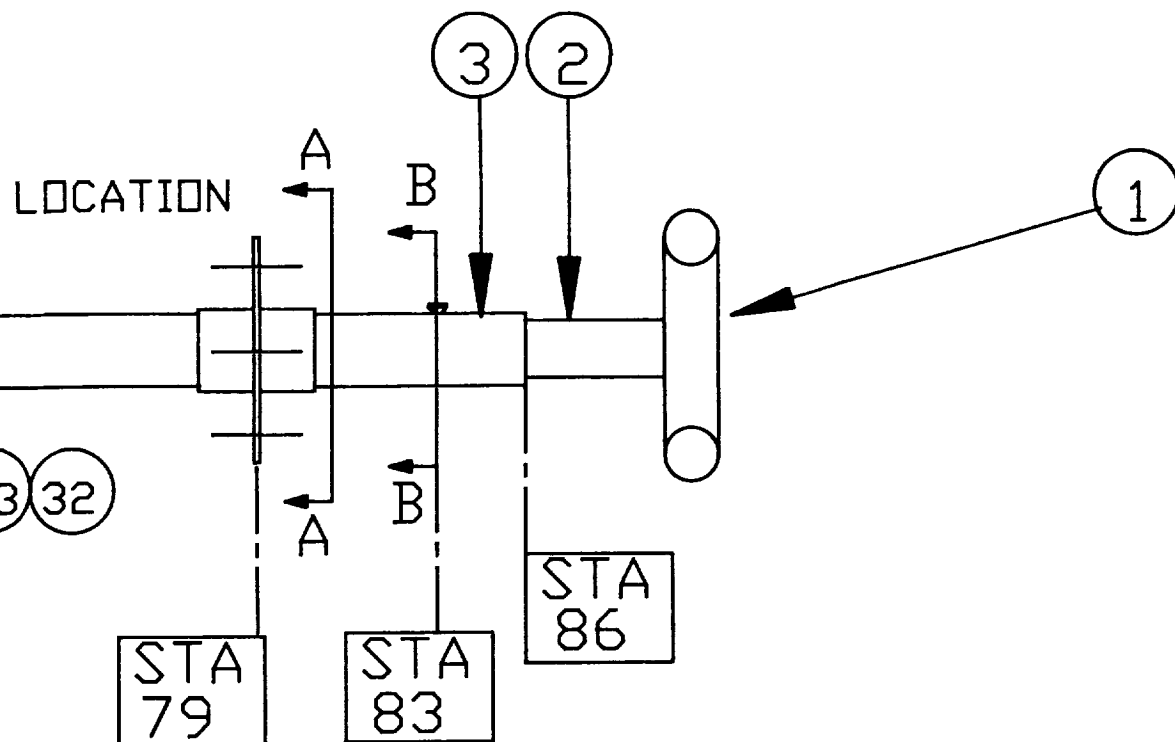
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NOTE: DASH INTERFACE IS AT STA 79.

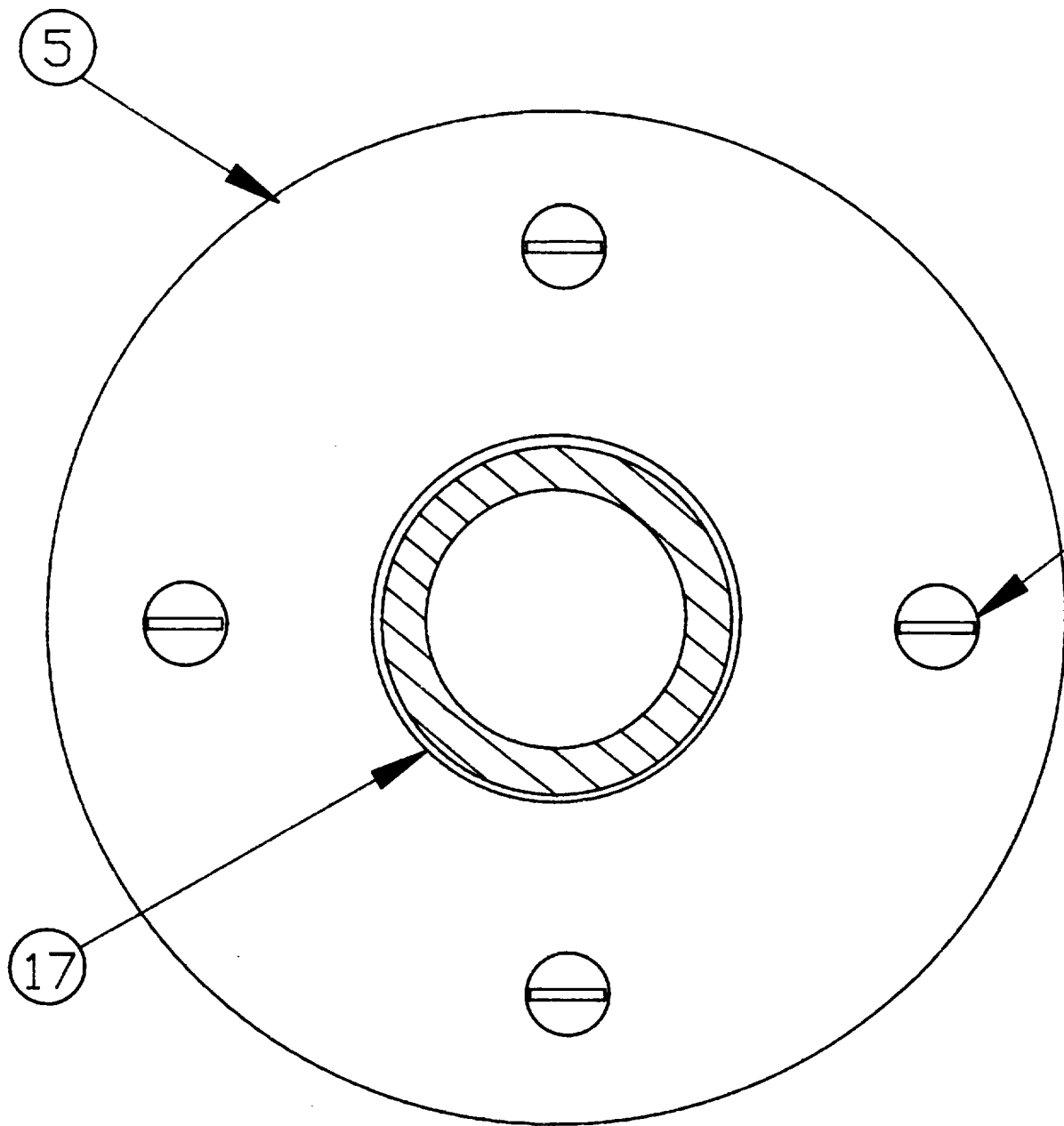
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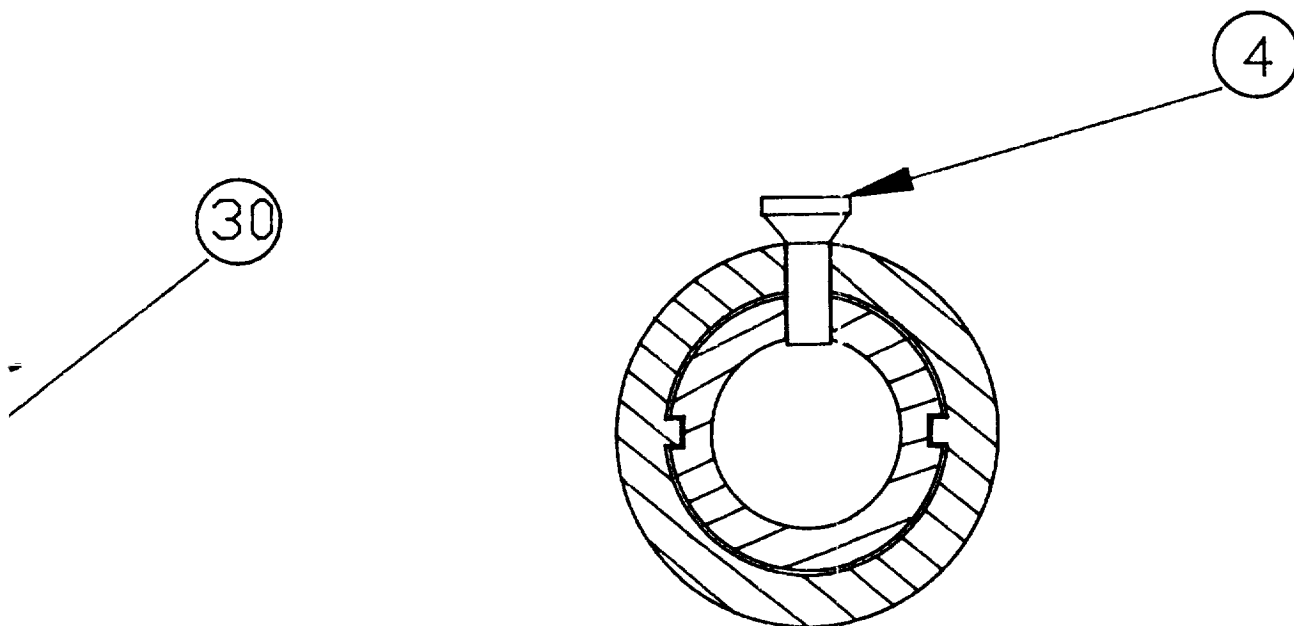


DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL		EMBRY-RIDDLE AERONAUTICAL UNIVERSITY DAYTONA BEACH FLORIDA			
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ANGULAR		TITLE			
± 1/2°	ELEVATOR YOLK SHAFT ASSEMBLY				
DRAWING NO.				SHEET	
421S9303D105				10F2	

FOLDOUT FRAME



SECTION A-A



SECTION B-B

DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL .XX ± .01 .XXX ± .001 ANGULAR ± 1/2°	EMBRY-RIDDLE AERONAUTICAL UNIVERSITY DAYTONA BEACH FLORIDA			
	SIZE B	DATE 3-15-93	SCALE FULL	DRAWN BY DAVID PAUFLER
		TITLE ELEVATOR YOLK SHAFT ASSEMBLY		
		DRAWING NO. 421S9303D105		SHEET 20F2

FOLDOUT FRAME

37	01	BEARING	DW
36	03	IDLER ARM MOUNT	4213
35	02	BALL JOINT	AN2
34	01	CENTER CRANK MOUNT	4213
33	04	ROD END CASTING	4213
32	08	PEDAL MOUNT	4213
31	04	LOWER PEDAL	4213
30	04	UPPER PEDAL	4213
29	19	ROD END	NAS
28	20	BRAKE LINE PER FOOT	MS2
27	01	SCOTT PARKING BRAKE VALV	4213
26	01	BRAKE RESERVOIR	ACSA
25	04	CLEVELAND MASTER CYL.	10-5
24	08	BEARING INNER RACE	SIE1
23	08	BEARING	BCH1
22	22	BEARING	LHA
21	75	AIRCRAFT WASHER	AN9
20	75	CASTLE NUT	AN3
19	19	AIRCRAFT BOLT	AN4
18	04	AIRCRAFT BOLT	AN4
17	32	AIRCRAFT BOLT	AN4

2,
FOLDOUT FRAME

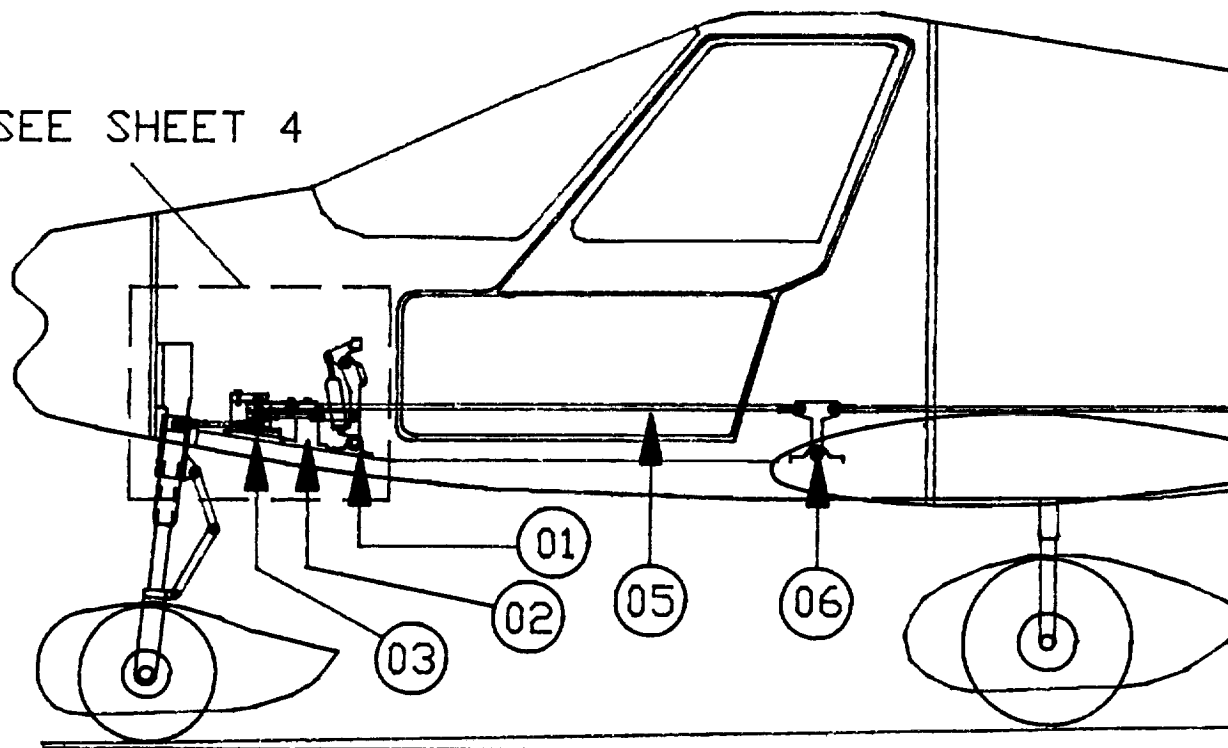
	16	18	AIRCRAFT BOLT	AN4-12
K	15	02	AIRCRAFT BOLT	AN4-16
9303D158	14	02	CIR. ROD 4130 9 IN.	421S9303D14
76-6	13	06	CIR. ROD 4130 6 IN.	421S9303D128
9303D156	12	01	GEAR BELL CRANK	421S9303D128
9303D154	11	01	TORQUE TUBE ASSEMBLY	421S9303D12
9303D152	10	01	CIR. ROD 4130 23 IN.	421S9303D128
9303D150	09	01	REAR BELL CRANK	421S9303D120
9303D148	08	01	CIR. ROD 4130 50 IN.	421S9303D118
560-R4-11	07	01	CIR. ROD 4130 37 IN.	421S9303D116
3741	06	03	IDLER ARM	421S9303D114
9303D146	05	02	CIR. ROD 4130 51 IN.	421S9303D112
4315	04	01	RGHT PEDAL ACTUAT. CRANK	421S9303D110
B	03	01	LEFT PEDAL ACTUAT. CRANK	421S9303D108
212	02	01	CENTER CRANK ASSEMBLY	421S9303D106
612	01	04	PEDAL ASSEMBLY	421S9303D104

-4	ITEM	QTY	DESCRIPTION				PART #
50-416	DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL .XX ± .01 .XXX ± .001 ANGULAR ± 1/2°		EMBRY-RIDDLE AERONAUTICAL UNIVERSITY DAYTONA BEACH FLORIDA				
0-4			SIZE B	DATE 2-22	SCALE 1/20	DRAWN BY RUSS SNOW	
-14			TITLE RUDDER CONTROL ASSEMBLY				
-26			DRAWING NO. 421S9303D102				SHEET 1 of 4
-10							

1.

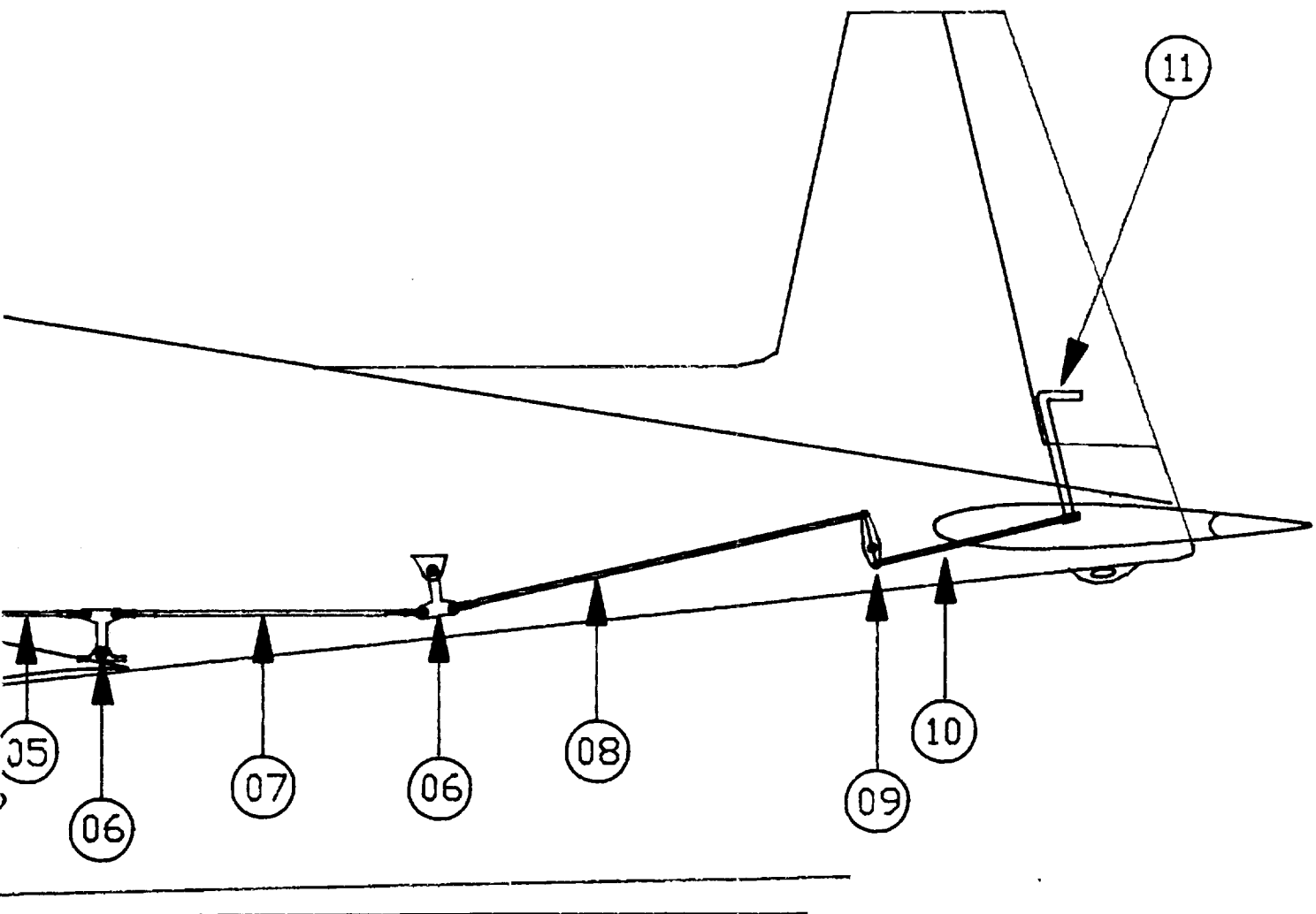
FOLDOUT FRAME

SEE SHEET 4



2.

FOLDOUT FRAME

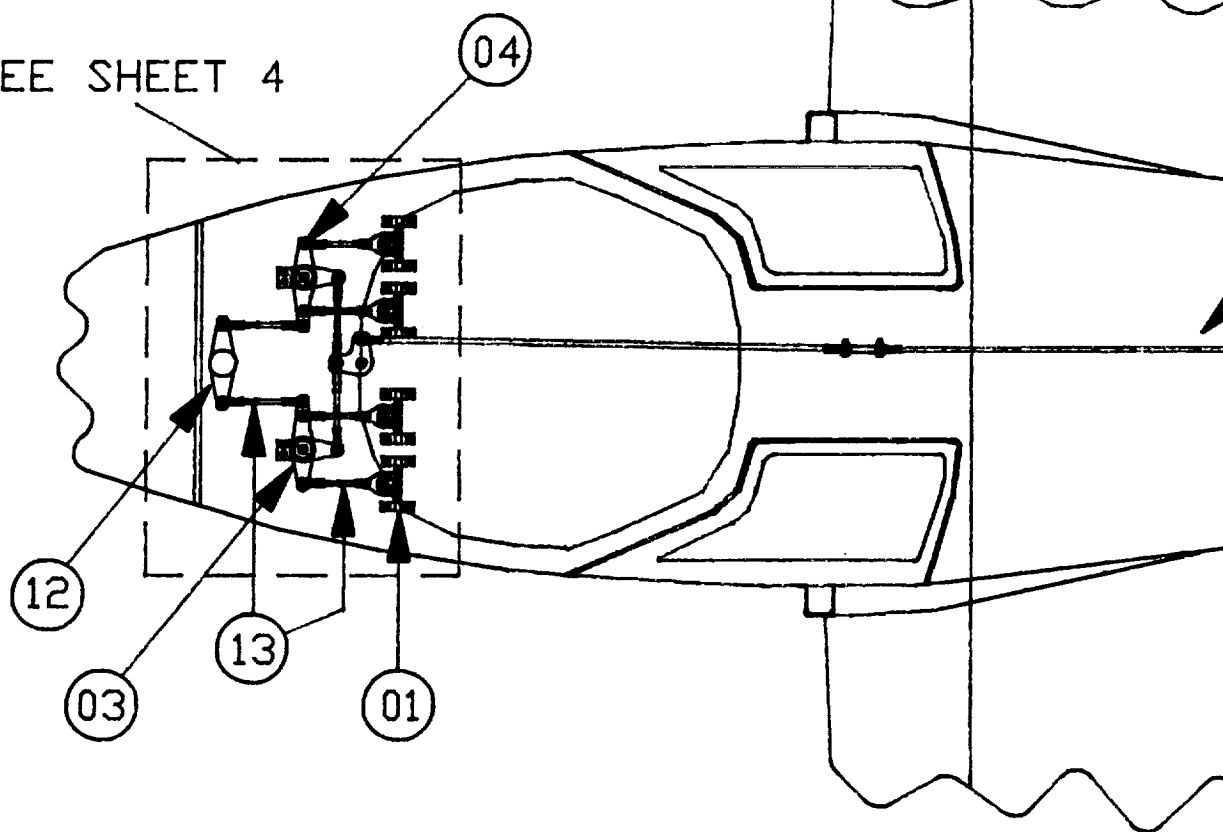


SIZE B	DATE 2-22	SCALE 1/20	DRAWN BY RUSS SNOW
TITLE RUDDER CONTROL ASSEMBLY			
DRAWING NO. 421S9303D102			SHEET 2 of 4

1.

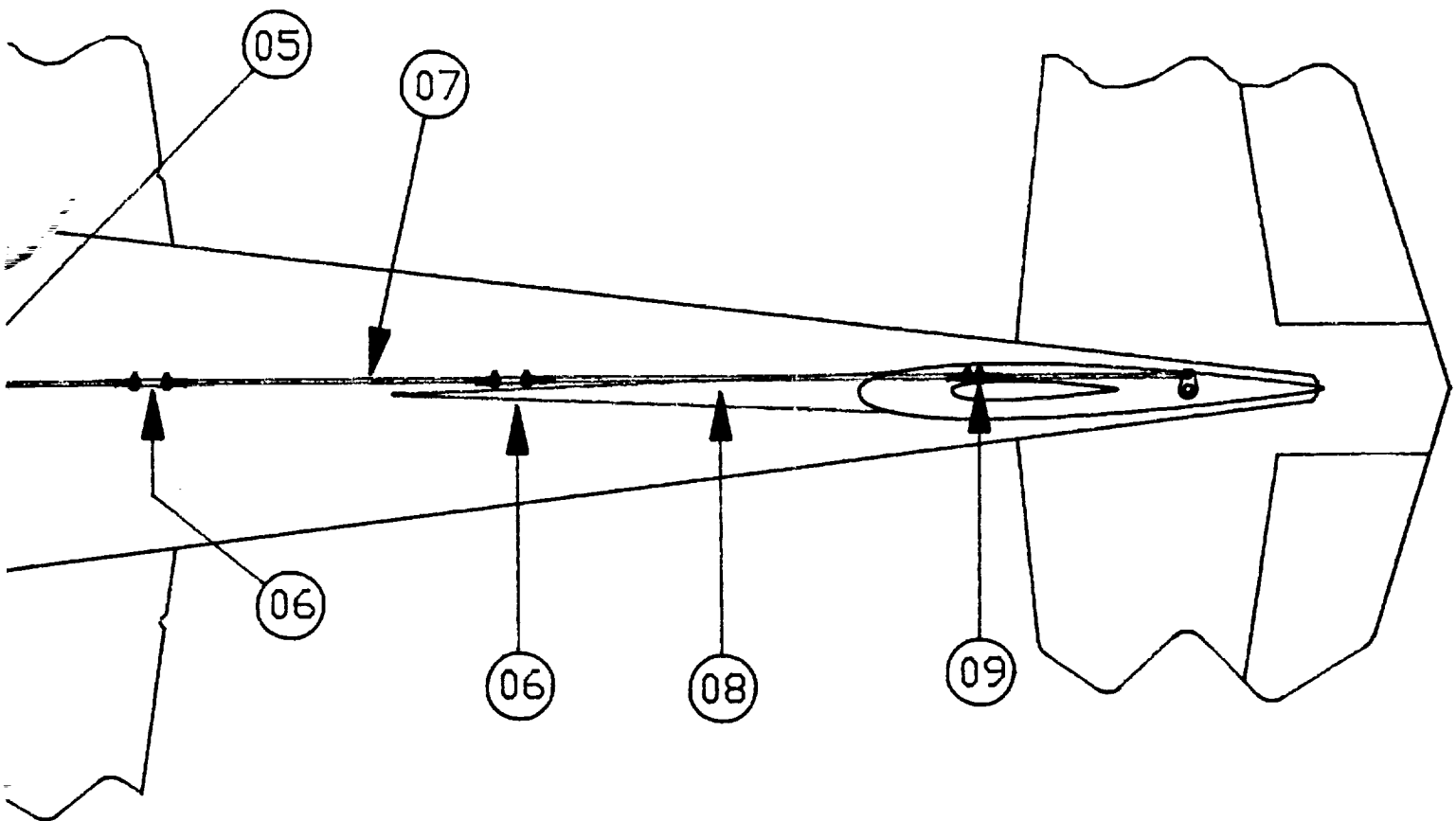
FOLDOUT FRAME

SEE SHEET 4



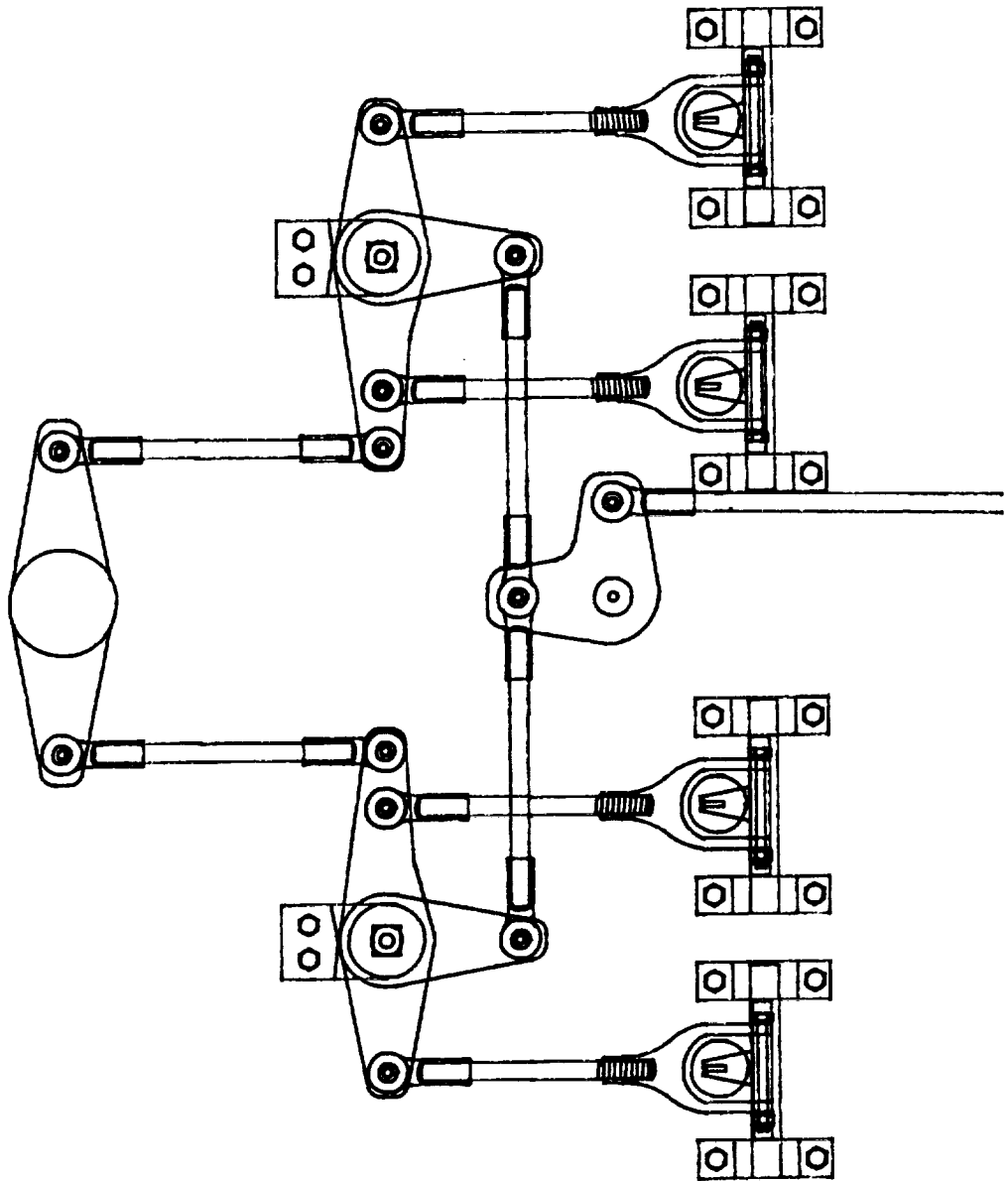
2.

FOLDOUT FRAME



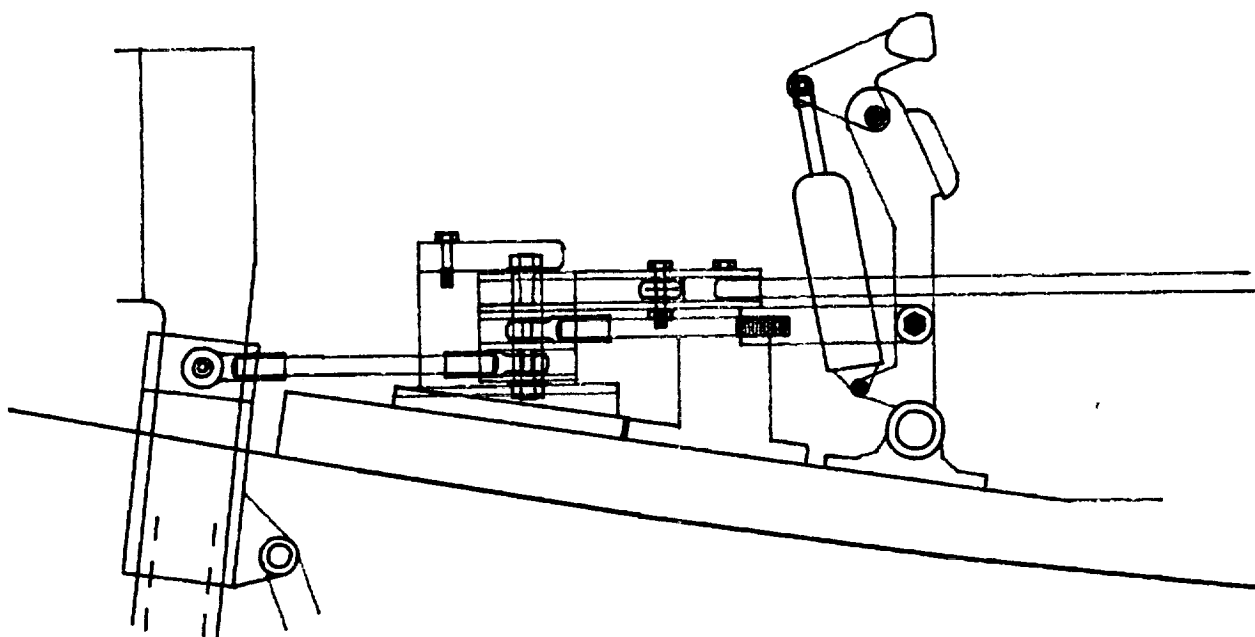
SIZE B	DATE 2-22	SCALE 1/20	DRAWN BY RUSS SNOW
TITLE RUDDER CONTROL ASSEMBLY			
DRAWING NO. 421S9303D102			SHEET 3 of 4

1.
FOLDOUT FRAME



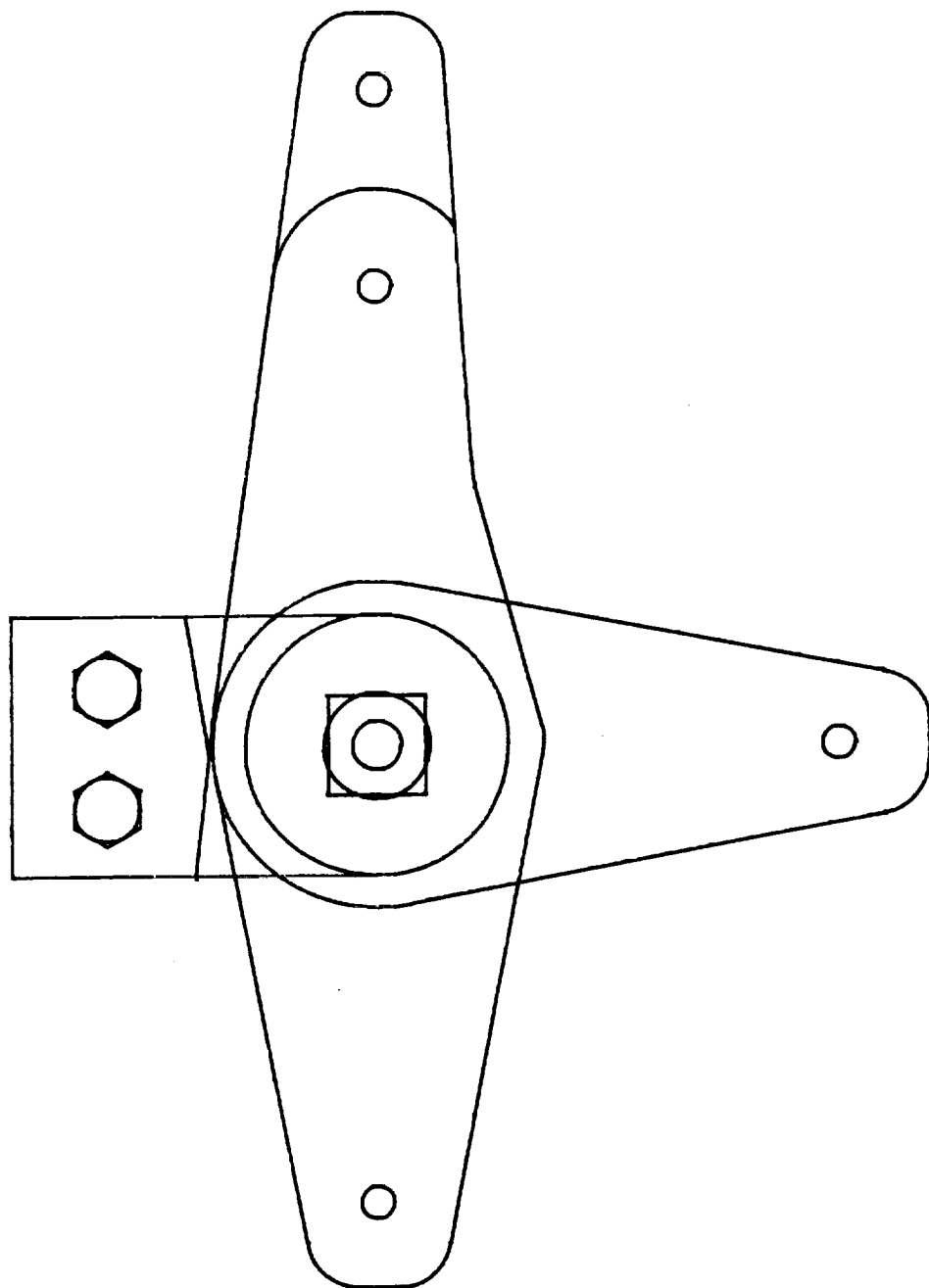
2.

FOLDOUT FRAME



SIZE B	DATE 2-22	SCALE 1/5	DRAWN BY RUSS SNOW
TITLE RUDDER CONTROL ASSEMBLY			
DRAWING NO. 421S9303D102			SHEET 4 of

1.
FOLDOUT FRAME



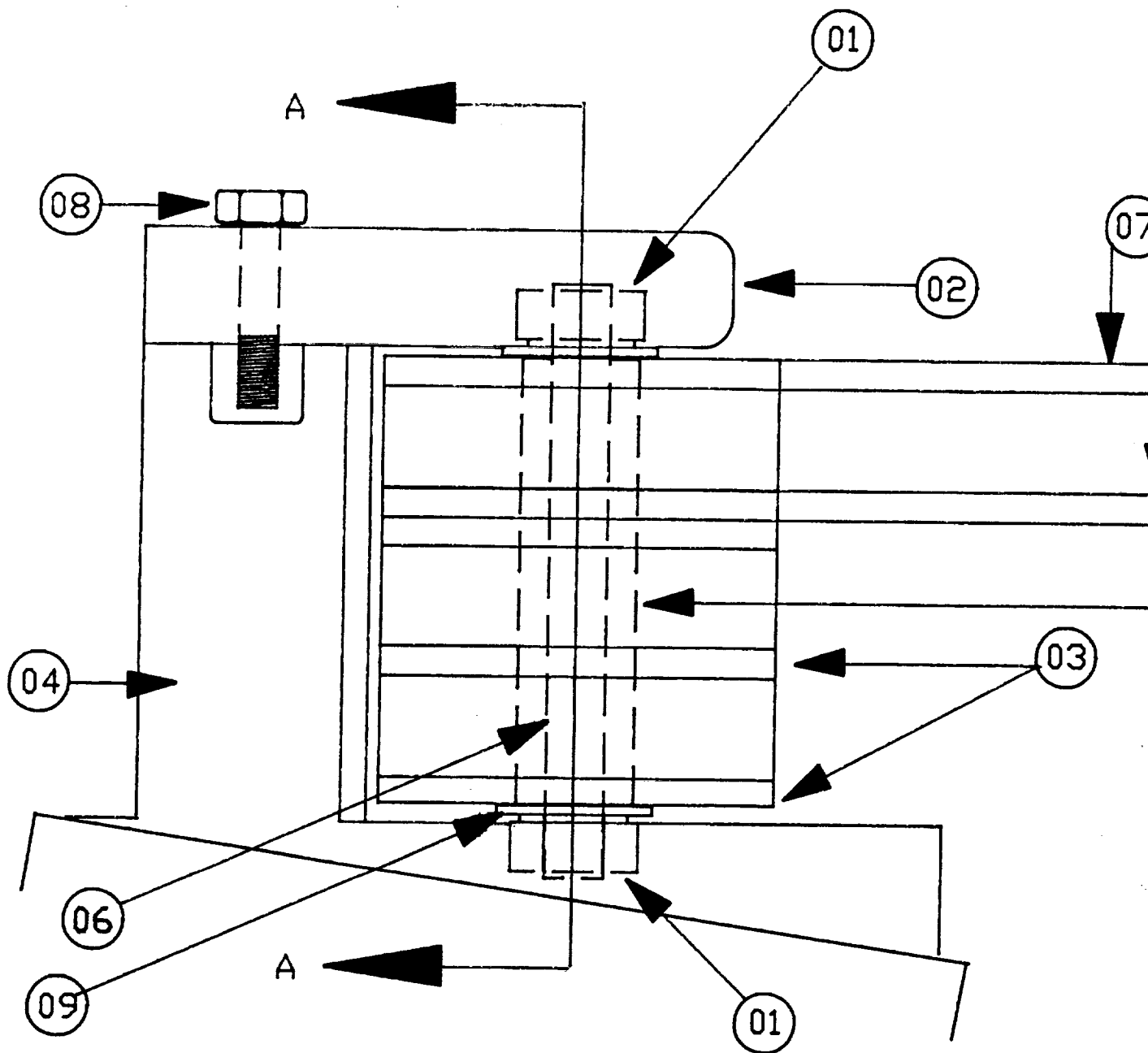
2.

FOLDOUT FRAME

09	04	WASHER 4130	421S9303D142
08	04	AIRCRAFT BOLT	AN4-11
07	04	PEDAL CRANK PLATE, UPPER	421S9303D140
06	01	3/8 INCH STEEL ROD	421S9303D138
05	01	SQUARE EXTRUSION	421S9303D136
04	04	BOTTOM MOUNT, PEDAL CRANK	421S9303D134
03	04	PEDAL CRANK PLATE, LOWER	421S9303D132
02	02	TOP MOUNT, PEDAL CRANK	421S9303D130
01	04	BEARING	LHA-6
ITEM NO	QTY REQD	DESCRIPTION	PART NUMBER

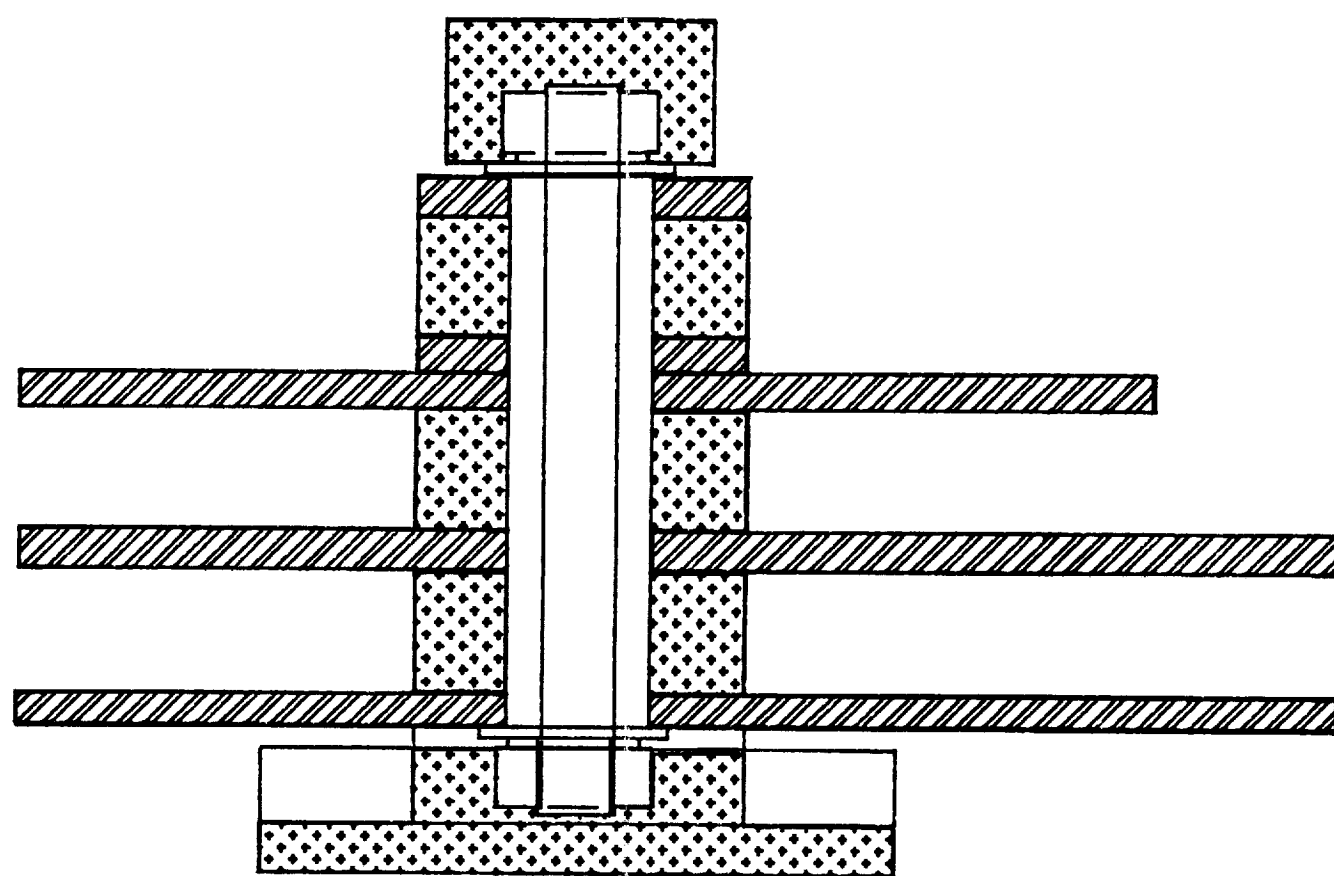
DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL		EMBRY-RIDDLE AERONAUTICAL UNIVERSITY DAYTONA BEACH FLORIDA			
.XX	± .01	SIZE B	DATE 2-22	SCALE 1/1	DRAWN BY RUSS SNOW
.XXX	± .001	TITLE			
ANGULAR ± 1/2°		PEDAL AND CRANK ASSEMBLY			
DRAWING NO. 421S9303D108					SHEET 1 of 2

1.
FOLDOUT FRAME



2.

FOLDOUT FRAME



SECTION A-A

SIZE B	DATE 2-22	SCALE 1/1	DRAWN BY RUSS SNOW
TITLE PEDAL AND CRANK ASSEMBLY			
DRAWING NO. 421S9303D108			SHEET 2 of 2